Food and Nutrition Security in the United States of America

Seasonal agricultural field workers, cut and package lettuce, directly in the fields of Salinas, California © Shutterstock

United States of America

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Agriculture plays a critical role in global food sustainability. Future production will be constrained by invasive pests and soil degradation, exacerbated by changes in climate and pollution. Addressing these issues requires the political will to support agriculture and natural resource infrastructure, including land-grant universities, agricultural research stations, international biological control centers, and an innovative private sector, interconnected with the international scientific network.

Summary

Globally, overall demand for agricultural products is expected to grow at 1.1% per year from 2005/2007-2050, down from 2.2% per year in the past four decades (Alexandratos and Bruinsma, 2012). Population growth, increases in per-capita consumption, and changes in diets leading to the consumption of more livestock products are the main drivers of expected changes.

Some potential national scenarios for agricultural production over the next fifty years

Increases in production are slowing due to a number of constraints. Land and water resources are much more stressed than in the past, both in quantity (per capita) and quality; there is soil degradation, decline in water quality, and competition from uses other than for food production. Growth of crop yields has slowed considerably. Climate change is a risk that would negatively affect agricultural production in many areas of the world. Questions are being asked about the sustainability of food production systems. As a result, "sustainable intensification" agriculture is now promoted (Royal Society, 2009; Nature, 2010; Godfray et al., 2010).

Over the next several years, the U.S. agricultural sector will adjust to lower prices for most farm commodities (USDA, 2015). For crops, production response to lower prices will result in reduced acreage planted. In the livestock sector, lower feed costs will provide economic incentives for expansion. Global meat consumption is projected to continue to increase, with poultry consumption rising faster than pork and beef consumption. Long-term developments for global agriculture reflect steady world economic growth and continued global demand for biofuel feedstocks. Those factors combine to support longer-run increases in consumption, trade, and prices of agricultural products. Reflecting these market adjustments and price projections, export values declined in 2015 and farm cash receipts fell in 2015-16 before both grew over the rest of the projection period. Farm production expenses will also increase after 2016, so driving net farm income will decline from recent record highs.

Technological improvements continue at an extraordinary rate. These developments are occurring not only in improving production, but also in improving efficiency. Any search of the web will show both classic companies and novel startups designing improvements in agricultural efficiencies. These efficiencies range from new genetic resources of production and disease resistance, to sensors that relate real-time information of soil fertility and water status to improve the effectiveness of irrigation and fertilizer applications, to self-driving machinery that can integrate sensor and remotely sensed environmental and plant status information into a computer-planned pattern of cultivation or harvest. The newer machinery can work using power

harvested from on-farm solar and wind renewable technologies rather than exclusively depend on large-scale inputs of fossil fuels that drive climate change and energy uncertainties. Precision agriculture is present, changing almost daily, and becoming integrated into real farming systems.

Newer applications of information and technology to work with our microbial partners, instead of destroying them, are beginning to allow for improving fertilizer and water use efficiencies and availabilities and attacking pests with reduced energy-inefficient pesticide applications that harm soils and people. Partnering among theoretical, university-based research, agribusiness, and farmers and ranchers is beginning to overcome the drop in research and development support as governments reduce support. These approaches have the potential to dramatically overhaul R&D and overall food security, across the U.S. and globally, for better or worse. The direction depends upon the approaches all parties take.

Finally, probably the cornerstone of sustainable agriculture is the attention to sustaining trade and creating an increasingly educated labor work force. Recent analyses of discussions of technological and social developments (Gopnik, 2017) point to the need to integrate R&D and social thought. As Gopnik (2017, p91) points out, "what separates modernity from antiquity... Guys who think big thoughts talking to guys who make cool machines- that's where the leap happens". We remain desperate for a comprehensive work force and international governmental awareness that understands the importance of international idea and commodity exchange, that focuses on the technologies that improve the environment while sustaining and enhancing agricultural production, and that takes the long view of worldwide human population growth and environmental, including climate, change, to create a sustainable global food production system. The Americas- the New World in many narratives- have the potential to provide both the leadership and the resources to create these integrative complexities. The alternative is not an option.

1. National Characteristics

The United States of America (U.S.) is the third largest country in the world in terms of physical size. Russia and Canada are both larger. Total area of the US is 9.8 M square kilometers, with roughly 685,000 square kilometers of water surface area (see https://www.cia.gov/library/publications/the-world-factbook/geos/us.html). Agricultural land makes up 44.5% of the country with 16.8% of this land designated as arable, 0.3% in permanent crops, and 27.4% in permanent pasture. Another 33.3% is forest. The majority of the U.S. lies within the temperate climatic zone, with small areas of tropical climate in Hawaii and the southern tip of Florida and arctic regions in northern Alaska. The country is environmentally heterogeneous, with most of the eastern half of the country having relatively high levels of rainfall, and a natural landscape dominated by temperate, deciduous forest. The central portion of the country has lower annual rainfall, with a landscape that is predominantly semi-arid to arid grassland. This gives way to arid and desert regions in the SouthWest quarter of the country. Major mountain ranges near the Atlantic Coast, in the West, and the western coastal region, and in an intermountain region, contain limited area that can be cultivated.

The U.S. is also the third largest country in terms of population, with roughly 323 M people. Both China and India have populations closer

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to 1.3 B people, so the U.S. is third in rank but has a much smaller population at a much lower population density than the two largest countries. The U.S. has a very racially diverse population and a relatively slow rate of population growth at ~0.8%. While U.S. gross domestic product per capita is high, inequality in wealth distribution contributes to considerable food insecurity. Roughly 42 M U.S. citizens face some degree of food insecurity, with the most frequent consequences including short-term hunger or persistent malnutrition. The problem of food insecurity appears to be increasing, partially due to stagnant wages for the working poor. Large governmental assistance programs and private charities are involved in addressing hunger and malnutrition, particularly in children.

Agriculture across the U.S. is also heterogeneous, but is predominantly industrial in scale. It is served by a large agricultural services sector that is chiefly composed of U.S.-based or European-based companies with major subsidiaries in the U.S. This includes equipment makers, fertilizer, seed, and chemical companies. Major crops include maize, soybeans, wheat, and alfalfa. Maize production has shifted heavily toward use in ethanol production, primarily as a light vehicle fuel, with the waste products of this process going to animal feed. Animal feed is one of the primary domestic uses of the two major crops, maize and soybeans. This contributes to a large animal agriculture industry that produces beef, pork, and poultry, including chicken and turkey. Poultry consumption, particularly chicken, has been increasing over the last several decades while pork consumption has remained constant and beef has seen a slow decline following a peak in the 1970s. U.S. beef production is somewhat unusual in that cattle are typically "finished" on grain in feedlots largely located near regions of extensive maize and soybean production.

The U.S. is self-sufficient in agriculture and is a major exporter of food and food products. However, because of a largely temperate climate, with distinct seasonality, the U.S. is also a major importer of food and food products. This includes a wide diversity of foods, including seafood, fresh fruits and vegetables (including many tropical fruits consumed in the U.S.), coffee, and specialty products including cheese, wine, and spices. Mexico and Central America are major sources of fresh fruits and vegetables, including both tropical fruits (e.g., banana, pineapple, and avocado) and crops that are "out of season" for much of the year in North America

2. Institutional Setting. National Agricultural Research Systems.

The U.S. has put into place a strong infrastructure to undertake research, evaluate and apply the results of fundamental research, and provide for training opportunities ranging from Elementary through Advanced Degree programs. Importantly, as issues such as climate change, invasive pests, ecosystem processes, and food production costs change, that structure can be augmented in multiple ways by topics outside of traditional agricultural programs, and by private initiatives. Some of these approaches are readily adaptable, others need support from agribusiness, education, and governmental programs.

There are multiple national agencies tasked with various aspects of food production and sustainability. The National Oceanic and Atmospheric Administration (NOAA) was initiated in 1807 under President Jefferson as the U.S. Coast and Geodetic Survey to survey and map the coastline for hazards and resources. It is now housed within the Department of Commerce. NOAA oversees the Sea Grant program focused on understanding and overseeing fisheries programs and sustainability. Given that the U.S. imports more seafood than it exports, and that seafood has been identified as an increasingly important resource, sustaining and reducing overfishing is clearly a critical element in the nation's sustainable food resources.

NOAA also manages climate and weather programs through the National Weather Service. Data range from predicting and tracking immediate-to-daily conditions and events to longer-range climate predictions and change analyses. Maintaining the infrastructure for this information and these datasets are essential for making short- and long-range planting, harvest, and crop choices for a sustainable resource.

An independent United States Department of Agriculture (USDA) was developed in 1862 to help small farmers, especially in newly (European) settled regions of the country. It officially became a cabinet-level agency in 1889. The Forest Reserve Act of 1892 initiated a management agency for the nation's forests through the Department of Interior, and was transferred to the USDA under the leadership of Gifford Pinchot and Theodore Roosevelt, as the US Forest Service in 1905 to concentrate on the nation's fiber production. Today there are over 90 Agricultural Research Service (ARS) labs in the U.S. and overseas and 67 U.S. Forest Research and Development laboratories organized into five regions plus the International Institute of Tropical Forestry in Puerto Rico, interconnected by a network of 80 experimental forests. Research and development in the broad areas of fiber and food production stretch across many topic agencies such as the Natural Resource Conservation Service (the old Soil Conservation Service), Research, Education and Economics (REE), the National Agricultural Statistics Service (NASS), and the Animal and Plant Health Inspection Service (APHIS). Together, these form the bulk of the agricultural and forestry R&D program across the U.S. and extend internationally.

Many other agencies have emerged to oversee specific tasks or agricultural issues. Frequently the missions of these agencies have shifted through the years. The U.S. Entomological Commission was founded, with $18,000 in 1876 within the Department of Interior in response to outbreaks of the Rocky Mountain Locust plagues. It was so effective that it apparently drove this particular species extinct (Lockwood 2004). This agency eventually became the U.S. Fish and Wildlife service, for managing wild populations of fisheries and game. These form the basis of subsistence food resources, managed by individual states, but supported through wildlife reserves, the Endangered Species Act, and other tasks to provide sustainable wildland resources.

The space program through the National Aeronautics and Space Administration (NASA) aimed its suite of tools and models toward sustaining food and fiber productivity, and eventually management through the Mission to Planet Earth, initiated in 1997. The National Science Foundation (NSF) funds research in basic science related to sustainable food and natural resource management, and more recently a number of public-private collaborative programs between NSF and such programs as the NSF-Bill and Melinda Gates Foundation Partnership has resulted in numerous high-profile efforts to boost agricultural production.

Universities and Research Institutes

The U.S. initiated a state-based agricultural research and assistance program in 1862, with the formation of Land Grant Colleges through the Morrill Act. Kansas State was the first such university in 1863, rapidly followed by Iowa State University, and agricultural programs at Yale, Cornell, and Rutgers Universities. The Morrill Act was followed in 1887 by the Hatch Act, which provided federal funding for Agricultural Experiment Stations (AES) in each state. The experiment stations provide some direct, but mostly collaborative funding and research connections between federal and state researchers focused in almost every agricultural activity nationally. In some states, such as California, there are three campuses of the University of California system that support AES, UC Riverside in southern California, and UC Davis and UC Berkeley campuses that maintain different specialties. Currently there are agricultural universities in every state and the District of Columbia plus associated territories (American Samoa, Guam, Northern Marianas, Puerto Rico, and Virgin Islands). At most of the universities, there are associated USDA research stations and facilities. Together these constitute a formidable research unit that addresses topics related to food and fiber production utilization, nutrition and transport. These range from biotechnology to remote sensing, to human nutrition, to agricultural economics and productivity. This system supports the most sophisticated network of modeling and instrumentation (sequencing, remote sensing) geared toward sustaining agricultural production in history. Just as important, by physically and remotely (using computer and satellite communication mechanisms) integrating university, state, and federal research facilities, inter- and transdisciplinary teams can address both immediate and long-range projected issues that emerge, or that arise from model predictions.

This research support was followed by the Smith Lever Act of 1914 that provided for the Cooperative Extension CE) Services in every state. The program was formed to ensure that research was translated from the research universities directly to growers and practitioners. In general, there are CE offices in every county, or group of counties, across the country. These are designed to address specific, local agricultural issues as they arise, and to provide a communications pathway to researchers to address emerging problems, such as those addressed elsewhere in this document.

Skilled work force development and the status of national education systems

Between 2015 and 2020, nearly 58,000 average annual jobs for graduates with bachelor's or higher degrees with expertise in food, agriculture, renewable natural resources, or the environment are anticipated. Almost half of the opportunities will be in management and business and 27% will be in Science, Technology, Engineering, and Mathematics (STEM), 15% in sustainable food and biomaterials production, and 12% in education, communication, and governmental services. Approximately 35,400 new U.S. graduates with expertise in food, agriculture, renewable natural resources, or the environment are expected to fill 61% of the expected 57,900 average annual openings. This leaves a deficit of 22,500 annual jobs openings which will be filled in related disciplines (biology, business administration, engineering, education, communications, and consumer sciences). Graduates with expertise in food, agriculture, renewable natural resources, and the environment are essential to our ability to address the U.S. priorities of food security, sustainable energy, and environmental quality. Graduates in these professional specialties not only are expected to provide answers and leadership to meet these growing challenges in the U.S., but they also must exert global leadership in providing sustainable food systems, adequate water resources, and renewable energy in a world of population growth and climate change. U.S. higher education programs have encountered challenges enrolling women and ethnic minorities in STEM specialties.

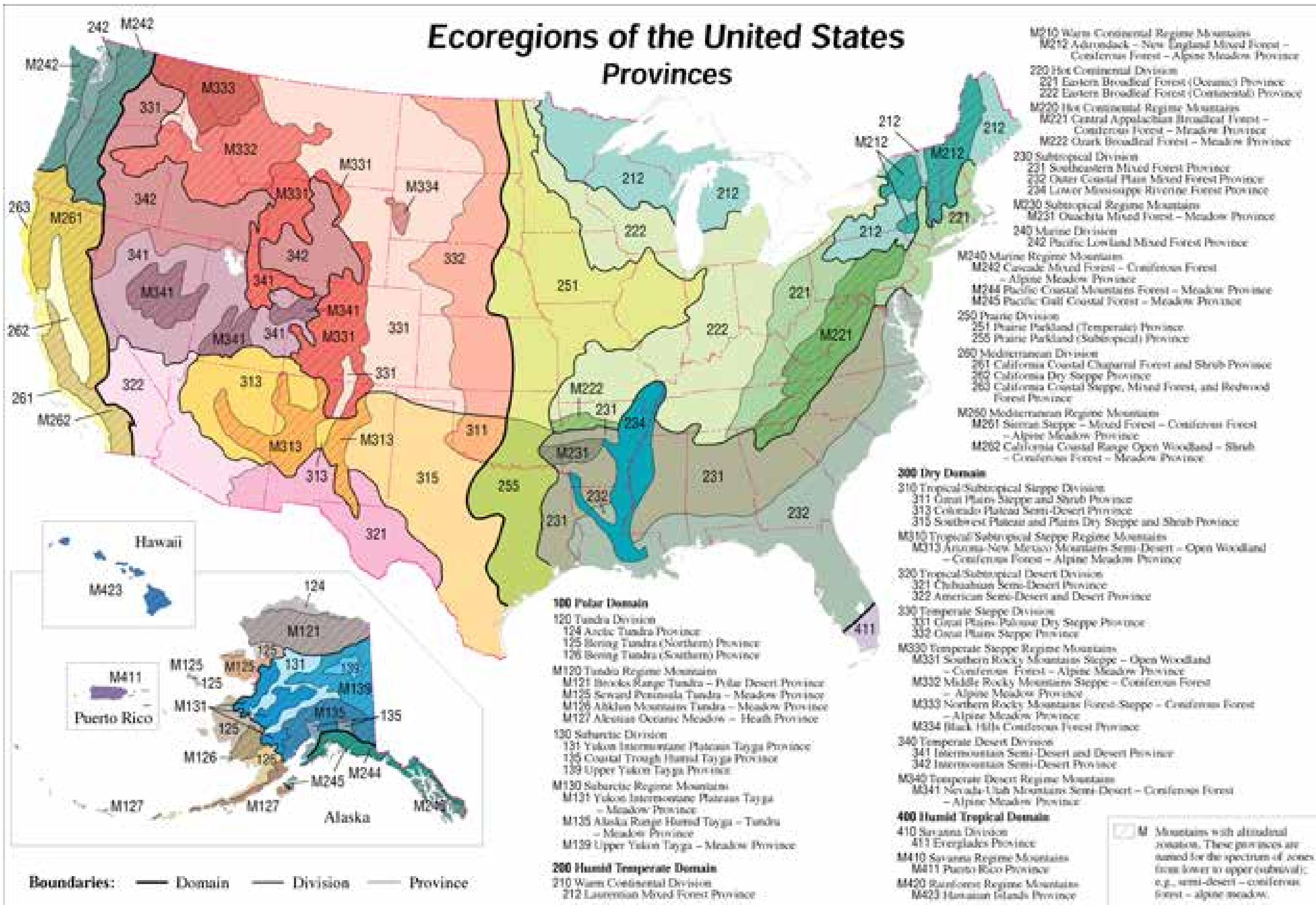
Relative contributions from public and private sectors

Federal and state support has formed the mainstay of agricultural Research and Development (R&D) since the mid-1800s. Over the past decade, federal funding has dropped within the U.S. However, overall support for R&D has remained stable, largely due to an increasing private sector (Fuglie and Toole 2014). In the past, most private investment in agricultural R&D was tied to postharvest and transport, machinery, and chemicals and fertilizers.

With the dramatic changes in variety developments, and the newer patent protection laws, rulings and federal and state support have dramatically changed the R&D landscape. As there is now patent protection for organisms and genes, R&D that is less transparent, and the greater difficulty to simply transfer from farmer to farmer has emerged. In Europe and scattered regions of the Americas, extensive grassroots objections have emerged to some applications of the transfer of genes between organisms. However, research continues to show that organisms, especially plants and microbes, naturally acquire genes from unrelated organisms, and newer CRISPR technologies that edit rather than transport new genes, may well address many of these concerns.

Future Outlook

We envision rather dramatic changes in institutional settings for agricultural R&D as we look across a 50-year timeline. These



Source: R.G. Bailey [Ecoregions of the United States, USDA Forest Service (scale 1:7,500,000, revised 1994)]

include a shift in local issues from the larger agricultural universities to smaller, often small colleges or community colleges. The research universities, in many cases the AES-associated universities and federal labs, will concentrate on larger, networked research questions, often in interspersed connectivity with industry. These will range from biotechnological approaches for seed production, and a biotech private-public partnership to manipulate, patent, and manage mutualistic microbial symbionts that reduce the need for pesticides and make efficient use of fertilizers. We also envision an increase in scaling of agriculture using government products such as remote sensing and a private industry interfaced with university engineers developing machinery that utilizes sensors and remote sensing outputs to improve land management efficiencies.

Two challenges for R&D include increasingly complex and cumbersome bureaucratic oversight and utilization of the results of R&D. Overlapping and often contradictory rulings ranging from health, to public interest, to transportation can hamper both R&D and the translation of R&D into the production sector.

Funding from the federal, state, local, and private sectors remains essential. The drop in federal R&D over the past decade may result in a drop in critical understanding of issues, especially pest evolution, which is emerging in the U.S. and globally. While the emergence of private funding has the potential to provide incredible new products and procedures improving food and fiber production, the detrimental impacts of patents and the potential for cost escalation remains of concern. Finally, support for continued training of future scientists both within the U.S. and internationally is essential to keep up with the world's still-growing population.

Within this realm, international cooperation and the creation and maintenance of scientific networks and open information exchange is critical for sustaining agricultural production.

3. Resource and ecosystem characteristics

Water resources and challenges over the next fifty years

Many of the world's aquifers are declining and are on a path many consider to be unsustainable (Richey et al., 2015). Current management, policies, and institutions in place are not sufficient to adapt to declining groundwater levels (Gold et al., 2013; Morton 2015). Groundwater policies, for example, vary by state and often lack adequate hydrologic and crop water use data to manage pumping rates (Wohlers et al., 2014). We lack an integration of scientific knowledge, policy scenario evaluation, and the political and social frameworks to extend the life of groundwater resources.

Soil resources and challenges over the next fifty years

Currently, U.S. soils experience soil degradation due to compaction, salinization, acidification, and contamination by anthropogenic compounds, but wind- and water-induced soil erosion that results in deteriorated physical properties, nutrient losses, and reshaped, potentially unworkable, field surface conditions remains the predominant driver (Karlen and Rice 2015). Adoption of conservation tillage helped reduce the potential for water and wind erosion. However, the overall average soil loss rate is one order of magnitude greater than estimated soil renewal rates, which are less than 1 Mg ha-1 per year (Alexander, 1988; Montgomery, 2007).

The second greatest threat to U.S. soils is loss of soil organic matter. Soil carbon levels are only about 50% of the level they were when land was converted from forests or prairies to farmland.

Transport of soil-derived Nitrogen (N) and Phosphorus (P) to waterways is a major problem, and excess application of N continues throughout much of the cropland in the U.S. Although a wide variety of best management practices for optimal nutrient application and erosion control have been developed and promoted, the problems of erosion and nutrient imbalance persist. The linkage of elevated soil N and P levels to water quality problems is exemplified by the seasonal hypoxia in the shallow coastal waters of the Louisiana shelf in the northern Gulf of Mexico (Alexander et al., 2008). The linkage between agricultural practices and N and P loads in waterways has been shown by many studies (Brown et al., 2011; Alexander et al., 2008).

The greatest uncertainty overall in our knowledge about the threats to soil functions lies in our limited understanding of the changes in soil biodiversity in the past and present and the implications of these changes for sustainable soil management. There is no reference baseline data for these organisms, nor do scientists have the ability to estimate the true numbers of soil organisms, particularly microorganisms. Many organisms have not been described and overall we need a better understanding of the biogeography of soil organisms in North America (Núñez and Dickie, 2014). As a result of our paucity of knowledge, assessing threats to soil biodiversity is very difficult. Regional- or national-level programs that monitor soil biodiversity are lacking in North America.

Energy challenges

Although concerns remain for the availability of fossil fuels for energy, we do not believe that this will be as important an issue as it has been for the past half-century. The emergence of new renewable energy technologies, especially for their application to agricultural lands, has tremendous potential in the future. Most farms and forests exist in areas with high potentials for solar, wind, or other renewable forms or combinations of energy-generating technologies. Local application of renewable energy for newly emerging machinery (electric vehicles) and the application of new microbial symbioses to overcome fertilizer limitations and replace pesticide needs has the potential to dramatically reduce the constraints imposed by limits on fossil fuels owing to climate change concerns, monopolizations, or limits on sustainable production.

Biodiversity conflicts and challenges

Agriculture in the U.S., and internationally, feeds the world using only a small fraction of the global plant and animal diversity. This diversity is largely comprised of species brought to the U.S. from elsewhere. Of equal significance, there are mutualisms and pests of pests (friends) that improve domesticated plant and animal production that we scarcely understand. Many of these species are uncharacterized. The greatest diversity of these potential partners exists in protected areas, semi-natural areas, or even around the edges of fields and forests. To sustain food and fiber production and simultaneously reduce fossil fuel, pesticide, and fertilizer overuse, we must improve the understanding, developing, and managing of these potential biological resources, to better manage all lands, including natural areas. This requires that we do a better job of researching and exploiting these potential resources all around us.

Only a few native U.S. animals and plants have been commercially utilized and fewer actually domesticated. Native Americans utilized a wide array of plant species, gathered a wide array of taxa, but farmed few native species. The primary agricultural crops were plant species imported from farther South. The exceptions are sunflowers, amaranths, and chenopods, annuals that grew well in disturbed soils similar to cropping of maize, beans, squash, and chilies. An exception may be pecans, an important nut tree, naturally growing in the southeastern U.S., but grown commercially in the southwestern U.S. There is an on-going discussion as to the potential for many more domestications among both plants and animals. There are no remaining large animals that could easily be domesticated. While bison is harvested and commercially sold, the actual domestication of bison is questionable; many researchers view bison ranches as more in common with wild rangelands. Importantly, extensive collections of pinōn, mushrooms, and other food sources indicate that there is a diverse array of potential crops that are less disruptive of soils and climate and that could potentially be domesticated. The preservation of biodiversity remains an important potential source of new agricultural productivity.

While the potential for new domesticated plants and animals continues to be debated, there is a strong potential for protection, selection, and utilization of mutualist symbionts that can increase the accessibility and efficiency of nutrients and water, provide pollinators, and provide protection from disease. Most of the mutualistic microbes employed (intentionally or not) in agriculture are from pre-agricultural ecosystems, or invade crops from surrounding ecosystems. Most crops and all trees depend upon mycorrhizal fungi for soil resources (nutrients, water), and almost none are intentionally transferred between countries. But most plants simply utilize the local microbial symbionts, regardless of source. source. A few microbes appear to have become invasive, such as *Amanita phalloides* and *A. muscaria,* and may well have both positive (nutrient acquisition) and negative (poisoning) attributes. Some N-fixing symbionts have also invaded agricultural systems and others (alfalfa, introduced from central Spain) are inoculated, wherein the original source populations are unknown. We do not know how diverse these populations are. For example, in analyzing the highly diverse ectomycorrhizal community only 69 of approximately 150 taxa could be matched, using a molecular approach, to known taxa with a 98% similarity criterion. Nearly two-thirds have similarity values as low as 85% and many are simply unknown. What we do know is that there is a vast array of responses from native and introduced populations from positive to negative. These responses often depend on the host, the soils, and the environment. In both the cases of mycorrhizal fungi and rhizobial N-fixers, there has been little selection or management among taxa to optimize plant production in the field. This means that there is a huge untapped microbial pool for enhancing resource acquisition as the environment shifts. *To reduce chemical and energy dependencies, symbiotic mutualisms hold a great deal of promise.*

In a similar vein, pollinators are absolutely critical to a vast array of crops. Most pollination is commercially undertaken by an industry managing European honeybees. Yet, because of many factors, including disease, mixing and migration of hives, and the use of pesticides, these commercial pollinators are becoming limiting to agricultural production. There are many native species that have enormous potential for improving crop pollination. Alkali bees are known to pollinate alfalfa fields in many regions across the western U.S. A vast diversity of bumblebees pollinate home gardens and commercial tomatoes. Work by many researchers have demonstrated that simply carefully managing field edges and waterways, along with neighboring wildlands, can sustain a diverse pollinator community and enhance crop productivity.

The vast biodiversity across the U.S. could improve disease resistance by providing pests of pests both within the U.S. and abroad. USDA European Biological control labs have provided numerous biological control agents for pests. Researchers across the country have found many pests of pests that can be utilized to sustain plant production. Examples include U.S. natural enemies of the Colorado potato beetle that are effective in beetle control both in the U.S. and in Europe. The glassy-winger sharpshooter is an insect native to the U.S. that transmits *Xylella fastidiosa* bacteria among a wide array of plants, including grapes, citrus, oleanders, sycamores, and even olives. The sharpshooter (*Homalodisca vitripennis*) is attacked by a native U.S. egg parasitoid, *Gonatocerus ashmeadi* (Hoddle and colleagues). This is an area that has only been marginally utilized for agriculture and has a remarkable potential to improve production while reducing pesticide dependency. Just as important, the potential to utilize native viruses, found in wildland ecosystems, to control disease microbes has not yet been effectively tapped. An example is the double stranded RNA (dsRNA) viruses. *Cryphonectria parasitica* is the causal agent of chestnut blight, changing a common and commercially important forest tree to an understory species that resprouts from older trees. dsRNA viruses can render *C. parasitica* hypovirulent and can facilitate tree regrowth. Many of these dsRNA viruses appear to be hybrids resulting from mixes of dsRNA from multiple sources. Importantly, dsRNA viruses are horizontally as well as vertically between hosts.

In general, there has been little effort to utilize natural biological resources in animal production. The isolation and application of bacteriophages for control of Salmonella is only one example of a search for biological controls. Moreover, an understanding of diseases in wild pig populations could prove to be a boon for the management of disease agents in domesticated pigs, thus for production. We predict that as antibiotic resistance increases, a clear need for alternative strategies could well come from the rich biodiversity surrounding all agricultural systems.

Broadly, there is an incredible biodiversity of useful insects and microbes, the potential for which has only been marginally tapped. Overexploitation of wildlands and loss of field and plantation margins in overzealous production efforts actually reduces or eliminates this diversity before it is studied and utilized. Maintaining wildlands, forests, rangelands, land margins, and riparian strips can play a critical role in sustaining future agricultural production. This will become even more apparent under climate change. We are already seeing a migration of mosquitos and mosquito-borne diseases northward, and with warming trends, expect an increased invasion by new pests of agricultural plants and animals. Understanding the ecology of these pests, their native host range, and especially their parasites and predators, is essential to designing new strategies to combat new emerging problems.

Implications of forestry trends

Forests in the U.S. have been a dominant feature of the North-American continent for millennia. Nevertheless, there have been dramatic shifts in cover, and utilization of forests, especially since European contact with the New World in 15th century. Following the heavy mortality in the human population in the Americas (including what is now the U.S.), there appears to have been a large reforestation of lands that reduced atmospheric CO_2 between 7 and 10 ppm – a dramatic shift in global CO_2 levels. In the 1630s, about 46% of the contiguous U.S. was forested land, which declined until the late 19th century where occupancy stabilized between 33-34% of the land area.

The forests are managed differently across the U.S., with 70% in public lands in the semiarid West (although the Pacific coastal forests are heavily privately owned) whereas the East is mostly privately held (81%) with public lands in highly dispersed patches, often in military-managed lands.

Importantly, non-lumber products are also important to local economies, including mushrooms, livestock, game, and arts and crafts. Forests are also crucial for ecosystem services, including sequestering 15% of the total greenhouse gases.

Growing forest tree stock volume is increasing in all areas, although especially in eastern U.S. Forests have played and continue to play a major role in ecosystem services. These include significant increases over the past two decades in carbon sequestration (15% of total greenhouse gas emissions), water production and purification (the Sierra Forests are described as water towers, providing irrigation water for the Central Valley and southern croplands of California), and biodiversity/endangered species protections.

Unlike agriculture, wood consumption has exceeded domestic production since the late 19th century. Although the 2008 recession reduced lumber production and consumption, still 79% of lumber was domestically produced and the remainder imported in 2011. That importation itself triggered the biggest threat to forest production through the continued import of disease agents. The chestnut blight fungus, *Cryphonectria parasitica*, is only one of the most dramatic examples, destroying the American Chestnut from the southern Appalachians to Michigan and New England. Many other serious diseases have come either from invasive microbes, such as *Phytophthora ramorum* in oaks (sudden oak death, moved through importing ornamental plants) or from (likely) native microbes spread by invasive insects, such as *Neonectria faginata* in beech, which rapidly spread by *Cryptococcus fagisuga*, a scale insect from Europe. Other insects are invading, ranging from the woolly adelgid Adelges tsugae of hemlock to the gypsy moths *Lymantria dispar* from Europe and Asia devastating to the northeastern oaks, to the goldspotted oak borer (*Agrilus auroguttatus*) being moved to southern California from Southeastern Arizona in firewood.

The largest impact on forest production into the future will emerge from the interactions of multiple threats, specifically invasive pests superimposed on pollution patterns and climate change. In the NorthEast, the woolly adelgid is migrating inland and northward as winter temperatures warm allowing greater survival of the insect. In the Sierras, ponderosa (*Pinus ponderosa*) and sugar pines (*Pinus lambertiana*) are showing massive mortality due to drought and bark beetles. Importantly, incense cedar (*Calocedrus decurrens*) appears to not be showing this mortality. Bark beetle damage is especially sensitive to drought stress. In an experimental nitrogen addition test, pinōn pines (*Pinus edulis*) were sensitive to N additions, simulating N deposition from air pollution, but not junipers (*Juniperus monosperma*). Importantly, junipers and incense cedar form arbuscular mycorrhizal symbioses, a primitive mycorrhizal symbiosis that appears to be less sensitive to drought and to high N than ectomycorrhizae found in pines. That the highest mortality is in the West slopes at the mid-elevation range, an area with high N pollution, presents a pattern reminiscent of the drought and tree mortality on the West-facing slopes of the transverse ranges of California in 2003. The drought impacts in both areas are exacerbated by forest fire suppression and subsequent stand densification. In the interior Rocky Mountains, a warming climate lengthens the drought period in Pinaceae forests and intensifies drought. With drought, warming, and fire prevention, bark beetle damage can be found from New Mexico to Montana. *A perfect storm of climate change, air pollution, invasive species, and mismanagement threatens the long-term production of forests of the U.S.*

Potential impacts of climate change

Population growth and the dynamics of climate change will also exacerbate other issues, such as desertification, deforestation, erosion, degradation of water quality, and depletion of water resources, further complicating the challenge of food security (Delgado et al., 2011). Increases in temperature coupled with more variable precipitation will reduce productivity of crops (Walthall et al., 2012). While the effects vary among regions of the U.S., all production systems will be affected to some degree by climate change. The continued degree of change in the climate by midcentury is expected to have overall detrimental effects on most crops and livestock. The predicted higher incidence of extreme weather events will have an increasing negative impact on agricultural productivity (Walthall et al., 2012).

Building resilience to extreme events

The vulnerability of agriculture to climatic change is strongly dependent on the responses taken by humans to moderate the effects of climate change. Adaptive actions within agricultural sectors are driven by risk, direct effects of climate change, and by changes in markets and policies, within the U.S. and worldwide. Effective adaptive action across the U.S. agricultural system offers potential to capitalize on emerging opportunities and minimize the costs associated with climate change. Delgado et al. (2011) listed several strategies to adapt to climate change in production agriculture including adjustments to inputs, tillage, crop species, crop rotations, and harvest strategies.

Future Outlook

We have known, since the classical studies of John Tyndall in 1861 and especially Svante Arrhenius (1895), that CO_2 molecules absorb re-radiated infrared radiation, retaining heat at the global scale. Global temperature data show that temperatures continue to increase, altering storm and ultimately precipitation temporal and spatial distributions. Every global-scale computer simulation model agrees that temperatures will continue to increase for a century or more at the least. Of greatest concern, not only the means are predicted to increase, but the variance also increases. Just as with any bell-shaped curve, the result is a dramatic increase in extreme events, such as extreme and prolonged high temperatures, and increased intensity and/or frequency of major storms. Pests are known to respond unpredictably to environmental change and extreme events. We project that novel pests, and increasing outbreaks from known pests, should be expected in the future. Agriculture must develop strategies to continue production under these conditions. It is important to recall that many of our beneficial organisms have existed under past spikes of high CO_2 and warmer environments caused by natural phenomena such as high volcanic activity (the Eocene Thermal Maximum). Working with the natural biodiversity capital of mutualistic organisms can provide new approaches and concepts to address the impacts of climate change and the overexploitation of land resources.

4. Technology and Innovation

Agriculture and food production have been impacted by many of the same trends that have resulted in rapid changes in general consumer products. For example, decreasing size and efficiency of microprocessors, sensors, and cameras that are used for mobile phones have found agricultural applications in pilotless “drone” aircraft. Drones are employed for remote sensing and collecting a wide variety of data in plant breeding and agronomic research. One advantage of drones for agricultural applications is that they are very inexpensive to operate; thus, they can be used with great regularity, resulting in time series data on crop field conditions. In a similar manner Light Detection and Ranging (LiDAR) that is being rapidly developed for use in self-driving cars can be employed in very similar precision agriculture applications. Agriculture is likely to continue to benefit from rapid technological advancement in areas such as artificial intelligence, real-time composite imaging from multiple cameras, and related technologies that have multiple applications for the general public and obvious extensions to agriculture.

Commercialization of biotechnology has developed more slowly. One of the most important early steps in the application of biotechnology to crop development began in 1994 with the commercial release of the Flavr Savr tomato. A large proportion of commodity crop production in the U.S. makes use of Genetically Modified Organisms (GMO) varieties. However, only four crops, canola, cotton, maize, and soybean, account for most of the production area planted with GMO. Insect resistance and herbicide tolerance are among the most common transgenic modifications, with virus resistance and altered oil compositions also found in two or more crops. The expense of development and of navigating the regulatory process associated with transgenic products, along with reluctance on the part of the general public to accept GMO products, have limited GMO applications.

The application of GMO technology to animals has been much more limited than in plants. Public acceptance certainly plays a role. Another consideration is that "single seed descent," self-fertilization, and high levels of backcrossing that are possible in plant inbred lines that are used for genetic transformation are not possible in mammals. In most animals, the presence of two distinct sexes and the detrimental effects of inbreeding mating designs will limit deployment of GMO. One notable exception with regard to a genetically modified animal is instructive. *Zebra danios*, a common freshwater aquarium fish that has been commercially available in the U.S. since 2003, has been modified with florescent proteins and is commercially available in a number of different colors. The Food and Drug Administration determined that because aquarium fish are not a part of the human food supply, they pose minimal risk to human health.

There is tremendous potential for novel agricultural products that build on the technological developments noted earlier. For example, DNA sequencing and genotyping of specific genetic markers has become much less expensive in the last decade. This has made it possible to identify large numbers of microbes by sampling soil, water, and even human and animal gut flora. The identification of much more diverse microbial flora in humans has resulted in novel treatments for gastrointestinal disorders. In a similar manner, the potential to survey soil microbes and microorganisms should make it possible to rapidly detect particular strains of plant pathogens and to more readily reintroduce or promote bacterial or fungal species that contribute to plant nutrition and productivity for particular crops. Sequencing also has many applications in detecting, tracking, and treating diseases in farm animals.

Targeted genetic modifications have the potential to result in a large variety of novel agricultural products. A much broader array of agricultural products are likely to be produced if organisms subject to a targeted genetic modification are treated as nontransgenic, thus not subject to standard GMO regulations. This is quite possible, because under many scenarios, an individual subjected to a targeted modification carries no evidence of that change (for example, no transgene), other than the change itself, which can be as subtle as a single nucleotide substitution. Targeted modifications have been proposed for a variety of applications, including modification of lipid composition in oil seed crops, changes in nutrient utilization, or changes in inflorescence type in cereals. Many additional applications are possible, suggesting that many more species could be subject to modification than has been possible for traditional transgenic products. Targeted modifications could also be used to treat specific genetically induced diseases, an application that might be particularly compelling in agriculturally important animals. However, the regulatory environment around changes in animals is likely to remain more stringent, in part because of concerns about animal welfare.

Pests, Diseases, and Mutualists

Pests and diseases of agricultural plants and animals have plagued human cultures throughout history and remain the single biggest challenge to agricultural production in the U.S. and globally. U.S. Agriculture has benefitted from three major processes: (1) the introduction of most major crops, leaving behind many disease organisms; (2) the ability of many crops to tap novel mutualists, enhancing stress tolerance, and (3) an outstanding, well-funded cooperative research interaction among federal, state, university, and private partnerships that can rapidly mobilize to identify, research, and attack diseases. However, all three are threatened by human travel, biodiversity loss, and funding priority shifts.

Theory of disease progression has been a major focus of research agencies and agricultural university scientists for as long as the agents of disease have been recognized. The identification of the causal agent of the Irish potato famine as *Phytophthora infestans*, a microscopic fungus, not humors, or vapors, or lightning, or even witches, led to the field of Pathology. Advances in basic understanding of disease from microbes to insects continues and is expected to continue into the future.

The emergence of the "enemy release" hypothesis shows how crop and tree disease issues continue to emerge and has major ramifications requiring both care for the transport and sale of products, the impacts of bureaucratic constraints on research, and the importance of collaborative international research. The vast majority of crops and animals used in the U.S. come from wild sources outside of the U.S. borders. When these were introduced, many of the diseases and the enemies of the enemy, critical for biological control, were left behind where the wild populations exist. With time and international travel and trade, slowly but inexorably these diseases continue to "emerge", and disperse to and infect important U.S. hosts. In some cases, the time frame for invasion can be very long, especially when an intermediate vector, such as an insect transmission species, must invade first, followed by the invasion of the actual disease agent, such as a bacterium or fungus. Historical examples include *Phytophthora* diseases of grapes, and current examples include the HuangLongBing (HLB) or "citrus greening" disease or swine influenza (H1N1). A variant is introduction of pests from related host taxa, such as the chestnut blight, *Cryphonectria parasitica*, on the American Chestnut (*Castanea dentata*) found naturally in the Chinese Chestnut, *Castanea mollissima*, which had evolved resistance to the *C. parasitica*. A third variant of the enemy release hypothesis is the emergence of hybrid strains from the introgression of genetic material from two or more original strains that results in one capable of infecting new hosts. An example is work on *Xylella* mulberry scorch diseases (Almeida and Nunney 2015).

Emerging "new" diseases will continue as long as there are crops. Further, as long as crops continue to be transported across borders, diseases will be transferred from a source population to a novel population. The only solution is the identification of potential threats through international cooperation among research agencies and universities, and the collaborative ability to search for and utilize biological control agents. The USDA European Biological Control laboratories located in France, Italy, and Greece is an outstanding example of cooperative efforts to identify and control diseases of important crop plants. Especially, the search for pests of the pests that become valuable control agents requires constant international cooperation. However, this potential could easily be lost if funding for collaborative efforts shifts, or if international collaborations are threatened.

A final concern is the loss of biodiversity associated with global change and with shifting land use patterns. The wild relatives of domesticated plants and animals have evolved resistance mechanisms that could be preserved and tapped by understanding and protecting the original gene pools. Just as importantly, microbial mutualisms provide protections beyond the genetic resources of the species itself. These mutualisms are also threatened by a general loss in wildland biodiversity as microbial symbionts often cross-taxonomic constraints of the individual species or populations.

Opportunities for and obstacles to new management technologies (e.g., in irrigation and water management or fertilizers) and policies

The current management, policies, and institutions in place are not sufficient to adapt to declining water resources (Gold et al.,2013; Morton, 2015). Groundwater policies, for example, vary by state and often lack adequate hydrologic and crop water use data to manage pumping rates (Wohlers et al., 2014). Considering nutrient management, many effective current technologies are not utilized because economic and social barriers impede their adoption (Davidson et al., 2015). The economic risk of applying too few nutrients is high. Providing excess fertilizers can improve yields with a marginal increase in cost, thus providing an economic margin of safety. A lack of obvious visible or tangible local environmental and economic consequences of nutrient losses can make further improvements of nutrient management a difficult sell. In most cases, groundwater pollution emerges downstream in space or in time. In addition, most farmers have significant demands on their time and labor, so that learning and adopting new practices requires strategies that are easily implemented and worth their time. In some cases, adoption of cover crops may be inhibited by government policies and crop insurance programs.

Development of aquaculture/ marine resources

The primary challenge to evaluating the sustainability of aquaculture and marine resources remains the need to continuously evaluate the localized and the aggregated production of aquatic environments and determine the fisheries' harvestability. This is especially difficult in aquatic ecosystems because the primary food resource tends to be organisms higher in the food chain. While some species used for human food are herbivores, most of these tend to be just above the base (primary producers) of the food chain. What we consider the desirable foods are either higher trophic structure (salmon, tuna, trout) or even detritivores (many shellfish).

The U.S. remains a net importer of edible fishery resources, importing more than triple the dollar value of exports. By biomass, domestic landings exceeded exports by nearly 10%, but catch was still below imports by approximately 20%. There is certainly considerable variation by species and by the particular product, but the trends in consumption remain steady to declining (http://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus15/index). In the context of food sustainability, U.S. fisheries are one of the more troubled topics-of-concern and in need of further research. Overfishing has been reduced, based on NOAA estimates, but 10-20% of commercial fisheries remain overfished in 2015 in the U.S.

Aquaculture remains a technology for a limited suite of commercial products, (e.g., salmon, oysters, clams, mussels, shrimp, catfish, tilapia) but provides a large fraction of the hatchery populations, contributing to both commercial fisheries and sport fishing. Although research in new technologies and how aquaculture interacts with ocean ecosystems is undertaken, this area has been clearly undervalued in the larger context of food sustainability within the U.S. As the population of the U.S. continues to grow, along with global populations, aquaculture will likely become an increasingly crucial food resource and contribute to the sustainability of fisheries broadly.

Threats to fisheries' sustainability continue to exist, in many cases, mimicking those of other areas of food production. These include pollution, invasive species, and global change, especially climate and direct impacts of elevated CO_2.

Aquaculture, once the greatest concern for pollutants and genetic declines in wild stocks, has become increasingly addressed by industry and regulation. There remain a number of critical issues, especially diseases, medications, and habitat quality. Care in the selection and escape of genetic modifications, whether intentional or simply selection in artificial environments versus the wild ecosystems, remains of concern. As we look toward a 50-year horizon, aquaculture will likely become an essential approach to fisheries' management both as an increasing food source and to reduce over-harvest from demands by U.S. and global consumers.

Pollution remains a critical problem for sustainable fisheries. Movement of nutrients and chemicals from aquaculture will likely be a growing problem as human population continues to grow and demands for aquaculture products continue to escalate. But oceans are not independent of terrestrial environments. Pollution by N and P from runoff has impacted fisheries and threatened fishery sustainability throughout history. Classical studies on places such as Waquoit Bay, Cape Cod, Massachusetts, have demonstrated that nutrient loading from development has dramatic impacts on estuaries, and even out into the open oceans, through wastewater and fertilizer impacts on N and P cycling (e.g., Bowen and Valiela 2004). Chesapeake Bay fisheries and seafood production remains detrimentally affected by development and by animal husbandry up the Potomac River. Efforts to improve the water quality of the Bay continue, often through simple approaches such as ribbon forest restoration.

Pollution, especially runoff, also appears to be a major driver of red tide and other harmful algal and cyanobacterial blooms that can produce neurotoxic shellfish poisoning.

Invasive species

As human populations become increasingly connected in both the amounts and speed of global trade and human movement, invasive species become of equal or greater importance than terrestrial invasions. There are multiple vectors, although improved understanding of invasions has reduced the impacts of some. biofouling of vessels, including recreational vessels, fishing vessels, and commercial shipping, all remain critical contributors to marine invasions. Moreover, imported seafood, ornamentals, bait, aquaculture, and ballast water all remain critical vectors. As Williams et al. (2013) and others have stated, there is a crucial need to address these impacts at the nexus of a multiplex of problems, and not simply focus on each individually.

Climate change has a variety of impacts on the sustainability of fisheries of the U.S. Temperature increases without doubt alter the composition of microbes, flora, and fauna of a particular region. Changes in global temperatures may well alter current global air circulation patterns with dramatic impacts on ocean circulation patterns. At more regional scales, water diversion patterns may result in the loss of critical links in complex food chains. An example is the Delta Smelt, a small native fish in the San Francisco and Sacramento-San Joaquin Delta that is dependent upon freshwater inputs and the freshwater/saltwater interface. With increasing drought coupled with water diversions to agriculture and urban developments, reduced and altered water flows threaten this small fish. Yet, this animal is a key link and indicator in the food chain that integrates the San Francisco Bay with the larger fisheries running off the California coast, including juvenile salmon and steelhead, and the larger species that depend upon these anadromous fishes.

Atmospheric CO_2 inputs affect more than just climate (Albright et al. 2016). Dissolved calcium is required by shellfish, such as oysters, mussels, and corals. Of importance to climate change, the oceans represent the largest sink for absorbing the increasing atmospheric CO_2. Since the 1950s, atmospheric CO_2 has increased from 320 ppm to over 400 ppm. Simultaneously, surface water ocean pH has gone from 8.13 to 8.03, a loss of 0.1 pH unit. As pH units, the measurement unit of alkalinity, are logarithmic, this means a nearly 30% increase in acidity. Decalcification decreases in dissolved carbonate in seawater as pH decreases. This means that the solubility of calcium carbonate increases and dissolution or reduced calcification then occurs. The calcium that builds shells of calcium carbonate for shellfish, such as oysters, mussels, and corals, is preferentially absorbed by the bicarbonate in the water caused by the additional partial pressure of CO_2. The result is increasing calcium carbonate in the water and the loss of shell formation and mortality of corals. These animals are not only important in themselves, but are builders of reefs, critical structural elements to ocean fisheries. This process has occurred before, so we know that this response is real. During the Paleocene-Eocene Thermal maximum, under a high level of CO_2 and a 5°C temperature increase, the pH of the deep ocean dropped and coral and shellfish production appears to have declined. About 300 million years ago, at the end of the Carboniferous, with high CO_2 and high global temperatures, coral reefs nearly disappeared. The impacts on global and U.S. fisheries remain unknown but are potentially highly significant.

5. Increasing efficiency of food systems

Prospects for technology based increases in agricultural production

Telematics allow navigation, prescription application, location, and other data to be transferred easily to and from farm machinery. These systems help farmers improve efficiencies in high-priced equipment.

Soil and crop sensors to monitor plant health, crop water needs, and soil nitrogen levels. These sensors enable on-the-go application of inputs based on real-time field conditions. Sensors help optimize water use and avoid yield loss. Optical-sensing technologies detect crop N levels that can communicate with application systems to apply the correct amount of nitrogen to meet crop needs.

Sensor technology also is available to measure soil features such as soil electrical conductivity, ground elevation, organic matter content, and pH. Another type of sensing system is satellite or aerial imaging to detect crop health, pests, and weeds. Growers can then apply nutrients and pesticides based on a prescription from the remote sensing images.

Biologicals are expected to increase in the future. Pest control and growth enhancements provide more environmentally-friendly and cost-efficient crop inputs. Advanced technologies such as high-throughput screening help to identify beneficial organisms.

Precision agriculture technologies are becoming more robust and more precise, ushering in an era of hyperprecision. The widespread adoption of navigation systems is driving the hyperprecision era and have allowed for precise and variable rate seeding and fertilizer applications. Controlled traffic systems, such as strip till and precise installation of drainage tile, are also possible with precision agriculture.

Automation is taking over operation of equipment, which allow operators to do more jobs with less strain and more accuracy. Some of the features include GPS steering, GPS headlands turning, conventional headlands programmable automation, automatic balers, automation of operator control of combines and forage harvesters, and automation of tractor operator functions like intelligent power management. Autonomous or robotic vehicles could be the next big change in controlled steering technology.

Seed companies are developing corn hybrids with the ability to better use available nitrogen by producing the same amount of corn with less applied nitrogen or improved yield with the same amount of nitrogen.

Radio Frequency IDentification, or RFID, has been widely used in livestock to identify animals. This technology will expand to crops to allow consumers to track individual products from cradle to grave as consumers want to know how farmers grow their food and what inputs they are using to determine environmental impacts.

Biotechnology allows alteration of many different factors involved in a plant's growth under water-restricted and high-heat conditions to find new keys to improving yields under environmental stress.

Infrastructure needs (e.g., transportation systems)

U.S. agriculture relies heavily on a transportation system that includes rivers, rail, and roadways.

Farmers and ranchers need the ability to move products, inputs (fertilizer), and equipment. U.S. transportation as a whole needs drastic upgrades to allow for efficient movement of goods. Agriculture is the largest user of freight transportation in the U.S., claiming 31% of all ton-miles transported in the U.S. in 2007 (Casavant et al., 2010). Much of this freight travels out of the country. During the past 5 years, half of U.S. wheat was exported, along with 36% of the soybean crop and 19% of the corn crop. These exports travel from the inland areas of the U.S. where they are produced to borders and ports by way of a network of trucks, trains, and barges. Trucking is critical for U.S. agriculture. The industry carries 70% of the tonnage of agricultural, food, alcohols, and fertilizers (Casavant et al., 2010). It links farmers, ranchers, manufacturers, and service industries to grain elevators, ethanol plants, processors, feedlots, markets, and ports. The first and last movements in the supply chain from farm to grocery store are by truck. Many agricultural products are perishable and time-sensitive, requiring the efficiency, special handling, or refrigerated services best provided by trucks. Existing bridge capacities requires investment in highways.

Significant and sustained growth in freight demand is expected, and could double by 2035 (Casavant et al., 2010). Investment in the railroad industry, however, is not expected to keep up with demand, especially in agricultural areas. This shortfall of investment could threaten the U.S. competitive position as a low-cost supplier of high- quality grain.

Barges offer a low-cost transportation alternative for moving crops and fertilizer. Barges move more than a third of U.S. corn exports and 17% of soybean exports through the New Orleans region along the Mississippi River (Casavant et al., 2010). The funding to maintain and rehabilitate the existing infrastructure needs to remain a priority.

Issues for food utilization and minimizing waste

In the U.S., 31% of the 195 MMT of the available food supply in 2010 went uneaten. Retail-level losses represented 10% and consumer-level losses 21% of the available food supply (Buzby et al., 2014). Recovery costs, food safety considerations, and other factors would reduce the amount of food that could actually be recovered for human consumption.

Food versus Energy

In terms of total production per unit land area and in number of permanent and migratory farm workers, the U.S. is easily the most productive country globally. However, U.S. agriculture is energy-dependent on foreign imports (40%) relative to other countries. Indeed, one of the primary limits to agricultural production in the U.S. is energy security (i.e., uninterrupted availability at an affordable price). Today, energy expenditures supporting U.S. agricultural productivity (e.g., equipment manufacture and use, fertilizer production) are among the largest expenses. In the coming decades, two additional conditions may further constrain production: (1) availability and affordability of energy used for fertilizer and pesticide production, and (2) a scarcity of land for both energy and food production. And, as most energy use remains tied to fossil fuels, CO_2 and methane production and release from agriculture into the atmosphere exacerbates global warming.

Over the past decade, observed and predicted shifts in the use of prime agricultural lands for biofuel production has raised concerns over their role in unintended land-cover changes (e.g., deforestation) elsewhere leading to no net positive or enhanced net greenhouse gas emissions ("leakage"). Demonstrating further complexity, many utility-scale renewable energy installations that may support, in part, the energy demands of grid-connected farmers are being sited on land that was previously natural or agriculturally productive. Site preparation for such large renewable energy complexes typically includes the removal of all aboveground biomass, soil compaction, road construction, and gravel and/or herbicide application. This siting behavior may expand greenhouse gas emissions through reductions or elimination of ecosystem functioning, not to mention the adverse effects on soil quality that may limit reversion back to agriculture. Energy development in the U.S. is now the leading driver of land-use and land-cover[1] change—augmenting losses from urban and exurban development. This trend poses serious land and energy challenges for U.S. agriculture and inhibits progress toward a more sustainable food system.

Nonetheless, careful consideration of financial incentives away from these extractive approaches could readily reinvigorate both food production and integrative energy and food production strategies. Use of solar or wind power generation along field edges, the built environment portion of farms, the salt-affected portion of lands, and floatovoltaics over reservoirs (that reduce algal productivity and potentially generate thermal transfers) could readily generate electrical energy for on-farm hybrid-powered vehicles and energy-intensive tasks. Every farm generates biological waste and diesel distillations at a range of scales are becoming available that could provide an important fuel source. Newer approaches to collect and utilize the energy from methane (CH_4) to CO_2 conversion at dairy or on-farm scales would also provide a powerful energy source immediately located on farms where the energy demands are high. As CH4 is 38 to 75 times as powerful a greenhouse gas as CO_2, this technological shift could be important both for future food production and for climate remediation.

In summary, the U.S. retains the most important food production system globally. Yesterday's agriculture is a major contributor to fossil fuel burning and global warming. Tomorrow's U.S. agriculture could readily utilize and depend upon on-farm energy sources and become a major solution to global warming.

1. land cover, a type of vegetation on the landscape, for example, crops, suburban housing, or forest.

6. Health Considerations Foodborne diseases

Foodborne diseases remain a major concern in agriculture

In fresh produce, approximately 48 million people get sick from foodborne diseases in the U.S. alone, where nearly 128,000 are hospitalized and 3,000 die annually. The major problem is fresh, raw foods, particularly of animal origin (mostly unpasteurized dairy and shellfish) and secondarily, raw fruits and vegetables. Despite high degree of incidence, the control mechanisms in the U.S. are refrigeration, pasteurization and cooking, and sustaining normal standards of water quality.

Four issues emerge as current and future challenges. These include spatial localization of agricultural activities, mishandling along a complex production chain, antiquated diagnostic tests, and antibiotic resistance. In many areas, animal production (feedlots for cattle, swine, chickens) co-occurs with the production of fresh vegetables. Locating feedlots upstream, or upwind of vegetable and fruit production, remains surprisingly common. Simple care in where differing agricultural production activities occur would easily remedy this problem. Care can also be taken as to timing of fertilization, especially manures, and making certain that high-quality water is used for fresh vegetable and fruit production. The complex and intertwining human and machine handling chain, between the producer and consumer, means that foodborne diseases can erupt at any point. New technologies that reduce human handling might reduce some points of disease agent insertion, but continued monitoring and maintenance, and re-design of equipment with food safety in mind, becomes of even greater importance.

Antibiotic resistance is an increasingly challenging arena for research and development. Foodborne microbes behave just like other pathogens. Antibiotic resistance is an evolutionary response by the microbes. Their resistance mechanisms include both rapid regeneration, thus mutation rates and horizontal gene transfer (Verras et al., 2013). These processes mean that resistance should be expected. For fresh vegetables, the sources could be upstream or upwind of animal production facilities, or even humans. Antibiotic resistance should be anticipated and predicted, and new conceptual approaches are needed.

The regulatory mechanism for detecting and anticipating disease emergence often remains plating and identification. This approach was necessary for the last century, but detection kits, rapid PCR (Polymerase Chain Reaction) approaches, and even rapid large-scale sequencing approaches are becoming less expensive and far more rapid. These approaches should be refined and incorporated nearly everywhere. The key issue for all foodborne disease is largely a mentality of safe food handling and careful preparation.

Overconsumption

In a world where concerns continue focusing on sustainability of food resources, an irony exists in that in many regions, the primary concern is overconsumption and obesity (e.g., CDC 2017). More than 36% of adults have obesity-related issues and the highest rates exist in some of the highest agricultural production regions of the country. A plethora of programs and strategies are available, and new approaches can be found at local, state, and national levels. Probably the most important contribution that our food and nutrition security perspective can contribute is to continue to point to the importance of sustainable, high-quality food production and distribution systems. These are documented throughout our report.

7. Policy Considerations

The national government of the U.S. provides support services, extensive research, and education programs to and on behalf of the agricultural sector. It also has regulatory authority to help ensure that the quality of food, both domestically produced and imported, meets modern health and safety standards. Most of the policies that govern these nationally based activities are administered by the U.S. Department of Agriculture, a cabinet-level ministry. The 50 states (and 6 territories) are also involved in agricultural policy making. State policies tend to be focused on the particular circumstances and prevalent crops in each individual state. Below several overarching policy considerations at the national level, related to food and nutrition security and the subject of on-going discussion and debate are enumerated.

Agricultural Support Policies

There currently exist a broad array of policies that provide direct economic support to agriculture in the U.S. These include policies that result in cash payments to growers and acreage limitations. The original intent of such policies was to stabilize the prices of agriculture output and buffer growers against prices so low that they could no longer afford to engage in agriculture. In recent years as the structure of U.S. agriculture has changed these policies have become less prevalent and their future less certain. Recent studies have shown that farm policies have little or no impact on food consumption patterns and the nutrition of the poor (Glauber, Sumner, and Wilde 2016). While it is often asserted that direct economic support to growers must be continued in order to enhance food consumption and nutrition among the poor, the evidence does not support that contention.

Policies of Direct Income Support and Targeted Programs to Alleviate Poverty and Advance Food Security Among the Poor

It is widely held in the U.S. that hunger, inadequate nutrition, and the absence of food security are problems of the poor. The policies focused on ensuring adequate nutrition and food security for all are, therefore, aimed at ensuring that the poor have adequate food and eat high-quality diets. There are three programs governed by these policies. The primary program is called the Supplemental Nutritional Assistance Program (SNAP). Eligibility to participate in this program is based upon income levels that approximate or are lower than the federally defined poverty level. Beneficiaries receive coupons or the electronic equivalent that average USD$125/month. The coupons can be used to buy foodstuffs but not fast food or alcohol. These latter restrictions are intended to ensure that beneficiaries eat a healthful and high-quality diet. For 2016 some 44.2 million people were enrolled in the program. The number varies with the economy with more enrollees during times of economic downturn.

The Expanded Food and Nutritional Education Program (EFNEP) is a community outreach program that operates through the Land Grant University in each state. The program is based on classes taught by paraprofessionals and the priorities are to emphasize the importance of diet quality, food safety, and food security as well as the management of food resources. The program also emphasizes the importance of physical activity. In 2016 80% of the families that participated in the program were below or near the federal poverty level. The program is also directed at youth, about 5 million of whom participate.

The Special Supplemental Nutrition Program for Women, Infants and Children (WIC) is a federal program that provides grants to states for supplemental food and nutrition education. Program beneficiaries are pregnant or breastfeeding women who have low incomes as defined by the federal poverty level. Non-breast feeding postpartum women are also eligible, as are infants and children who are not over the age of 5. In addition, eligibility requires that participants be at substantial risk nutritionally. This risk must be assessed by qualified health professionals at WIC Clinics or other medical facilities. Nutritional risk may be medically-based – such as anemia or underweight – and / or dietary-based – largely poor diets.

The policies upon which these programs are based tend to be noncontroversial though the levels at which they are funded, benefits and criteria for eligibility are sometimes the subject of legislative debate. Policies are clearly focused on the poor and on women and children who may be chronically undernourished. The programs that are based on overarching policies have educational components and sometimes restrictions that tend to ensure that resulting diets are of high quality. These programs also have educational components that emphasize food resource management. The policies that govern and guide these programs will be important elements in sustaining food and nutrition programs for the future.

Policies Supporting Agricultural Research and Technology Development

In the U.S. much agricultural research is carried out by the Agricultural Research Service in the U.S. Department of Agriculture and at the Land Grant Universities in each of the 50 states, the District of Columbia, and the 6 Territories. Additionally, there is a modest amount of proprietary agricultural research conducted in the private sector. Publically supported agricultural research has served the nation well by lowering the costs of food and fiber and by improving the quality of agricultural produce. In spite of this record, the U.S. invests significantly less in terms of dollars invested per dollar of gross domestic product than other developed countries that are agriculturally important. The level of this investment is an on-going policy issue.

There are studies that show that the internal rate of return on investment in agricultural research was 19% during the last half of the 20th century. During that period the percentage of food costs in the average family budget dropped significantly. Willingness to invest in public agricultural research will be important and as well as the related objective of applying science and technology to agriculture to providing adequate food, nutrition, and food security to future citizens as well as to the trading partners of the U.S.

Policies Facilitating and Enhancing Trade in Agricultural Products

In the absence of a globally catastrophic war or extensive isolation of nation-states from each other, the agricultural economy of the world is likely to become further globalized. The U. S. is an important actor in agricultural trade globally and an important actor in hemispheric trade. Mexico and Canada are among its most important trading partners. Effective policy making is needed to facilitate international trade and enhance the flows of produce, implements, and know-how through trade. It is important to recognize that both the U.S. and its trading partners gain from trade. The issue of whether the U.S. should be fully supportive of international trade in agriculture and treaties that govern such trade is now being debated nationally. Policies that constrain such trade and bar related treaties would certainly threaten the ability of the U.S. to be a significant and effective actor in efforts to improve food availability, nutrition, and food security globally and within the hemisphere.

Policies Related to the Protection and Enhancement of Complementary Resources – Land and Water.

Land and water are two critical inputs to agricultural production processes. Arable land is essentially in fixed supply. Although the supply of arable land in the U.S. is large it is not unlimited and careless management of it could result in increasingly tight constraints on agricultural production. Economic growth frequently leads to agricultural land conversion, often to urban uses. Overly intensive use of agricultural lands can lead to desertification, as in the Middle East, North Africa, and elsewhere. It could be visited upon the southwestern U.S, Both public and private land use management will need to be focused more intensively than it has been in the past if additional arable lands are not to be lost to production in the future.

Water is also a critical input to food production. Irrigated agriculture, which is practiced on roughly 7% of crop and pasture land in the U.S., accounts for approximately 3 % of the value of total agricultural production. Irrigated agriculture is the largest consumptive user of water in the country, accounting for about 80% of total consumptive use. In recent years, irrigated acreage has declined due principally to regional droughts and economic downturns. There are, however, a number of factors that threaten to reduce supplies available to agriculture that must be more carefully managed in the future. Groundwater overdraft is a problem for some regions where effective management is absent. Declining water quality limits supply just as surely as drought. The impacts of climate change are uncertain but require farm water management to become more adaptive than it has been in the past.

The policy problems surrounding land and water are complicated because the legislative and administrative authorities over land use, water rights, and on-farm water management rest with state and local government rather than with the national government. Nevertheless, such fragmentation of policy responsibility may be appropriate since requirements for managing land and water resources more effectively differ from state to state and region to region. National policies can be important in encouraging state action by providing financial support and specifying methods and the specific nature of the required response.

Space does not permit a comprehensive survey of all U.S. policy considerations related to the provision of nutrition, and food security. The five policy realms discussed previously are among the most important, however. Among the others are policies for protection of food quality and for combating foodborne diseases; policies to further promote healthful diets, and policies to promote better management of agriculture at the farm level. All are deserving of detailed consideration, debate, and action in the future.

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