# *An introduction to the global food security, technology and policy nexus*

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Food security as an emerging global concern is probably best dated from the founding of the Food and Agriculture Organization (FAO) of the United Nations in 1945. It is comforting that a sustained international effort to deal with one of the most pressing needs of all peoples of the world sprouted from the ashes of two world wars. It is reasonable that the vision of a world at peace would include a vision of a world where all people would be adequately nourished and in which agriculture – then the human activity that occupied more people than any other – would offer a fulfilling way of life.[1] However, it was clear that major increases in agricultural productivity were needed for sufficient food supplies to become a global reality. Famines were still a tragic part of human existence, with the Bengal famine of 1943 still a fresh memory.

There is no question that enormous challenges face us as we work to assure a sustainable and environmentally sound food supply for future generations. The FAO (2017a) *Future of Food and Agriculture* lays out these challenges and opportunities they present in an encyclopedic tapestry. Despite several years of encouraging decline, the number of undernourished people in the world ticked up to over 800 million. Nearly 25% of children show stunted growth (FAO 2017b). Human population is expected to grow to 10 billion by 2050 and food demand to increase by 50% (United Nations 2015a). As populations become increasingly urban, the type and quality of food in demand shifts. These changes, along with more sedentary lifestyle, present new challenges to agriculture: supply appropriate and healthy foods. The required future increase in food production matches that which was achieved in the unprecedented growth rates of the last half of the 20th century that themselves dwarfed the gains we have made throughout most of recorded human history. Now global food needs must be met while facing uncertain climate changes, political commitments to preserve Earth's environment, dramatic shifts in where people live, how they make their living and ultimately their expectations for what makes a decent life. Because food security is essentially a quality of life issue, the technical considerations around crop productivity quickly become entangled with public policy and politics.

The impact of the interplay between technology and policies on global food security is so vast that major pruning is inevitable if any areas are to be treated adequately within the space limits of a book such as this. The constraints imposed by this prioritisation can be managed to some extent by examining broad and important thematic areas, such as

biodiversity, crop improvement, human nutrition, government policies and trade; but for these treatments to be instructive, they must be placed within a real-world context. In this volume we take many of our examples from the major food staples, especially rice and wheat, in the major developing areas of the world, notably Asia and Africa, where most of the world's remaining very poor and hungry people live.

## Successes in global food security and second order problems

By the mid-20th century the glimmerings of a major revolution in agriculture were already visible. The Haber-Bosch process developed early in the century produced ammonia from the near limitless supplies of nitrogen in the atmosphere (Erisman *et al*. 2008). This ammonia became a source of inexpensive fertiliser that overcame one of the most serious limits to productivity in crop production: adequate nitrogen supply. Plant breeding, benefitting from early discoveries in genetics, was already producing much higher yielding hybrid crops, especially maize. Mechanisation was transforming agriculture in many parts of the world, replacing human and animal draft power with machinery fuelled by petroleum. And social movements were underway that would transform Asia and Africa from a colonial world ruled by European powers into one with many new nations.

In the 1960s stark differences in opinion emerged of how to tackle global food security. One school held that populations would inevitably outstrip global food supply, essentially expressing Thomas Malthus' 18th century predictions[2] in terms of 20th century ecological 'carrying capacity' of the planet. This was popularised by books such as *The Population Bomb* by ecologist Paul Ehrlich (1968) that maintained that population growth was already outstripping agriculture's capacity to supply enough food and that social and environmental catastrophes were unavoidable. Ehrlich argued that only some developing countries could hope to achieve food security with adequate investments in foreign aid, and merited support. Others, such as India and what would become Bangladesh, were beyond saving and should be left to fend for themselves. Rachael Carson's *A Silent Spring* helped focus the attention of a nascent environmental movement on the negative aspects of the impact of agriculture on the environment (Carson 1962).

Philanthropic entities such as the Ford Foundation and the Rockefeller Foundation, on the other hand, were investing significantly in education and research in developing countries with the explicit intent to increase staple food supplies. While accepting that population growth could not continue indefinitely, major increases in food supply could forestall the inevitable global disruptions that massive famines would cause. Indeed, Rockefeller Foundation scientist Dr Norman Borlaug eloquently made the point in his 1970 Nobel Peace Prize acceptance speech (https://www.nobelprize.org/nobel_prizes/peace/laureates/1970/borlaug-acceptance.html) that increases in food supply would buy time while the world invested in developing the social and political structures that eventually would slow population growth. Building on their earlier work in agriculture and rural development these foundations created the International Rice Research Institute (IRRI, www.irri.org) in the Philippines and the Centro Internacional de Mejoramiento de Miaz y Trigo (CIMMYT – The International Maize and Wheat Improvement Center, www.cimmyt.org) in Mexico with the purpose of developing improved strains of rice, wheat and maize. These were the first of eventually over a dozen international agricultural research centres dedicated to improving agriculture in developing countries and supported by an informal group of donors called the Consultative Group for Agricultural Research, or CGIAR (www.CGIAR.org).[3] The relatively modest investments in agricultural research were part of much larger

investments by international lending agencies and official development assistance (ODA) in education, rural infrastructure and irrigation.

The dire predictions of mass famine did not materialise, while the investments in research to develop much more productive varieties of wheat and rice paid off handsomely. Having fed humans for millennia, most staples at the time did not appear to have great potential to increase their yields. If fertilised or grown in otherwise very favourable conditions, they tended to add more leaves and stems rather than grain. Scientists transformed these staples such that they responded to fertiliser and water by at least doubling their grain output. Other changes allowed much shorter growing seasons, meaning that with irrigation in tropical and subtropical regions two or even three crops could be grown per year, where previously only one crop was possible. The resulting dramatic increase in staple food production in developing countries became known as the 'Green Revolution'.

By the late 1980s it was clear that famines – at least those caused by large-scale failure to produce enough food – had been averted. By the early 2000s, global food production had doubled, while cultivated land area increased by only ~10%. But the Green Revolution was not without its critics. Farmers often applied excessive amounts of fertiliser to their crops and changes in cropping patterns combined with susceptibility of the early modern varieties resulted in large pest outbreaks and excessive use of toxic pesticides as well. Large hydroelectric and irrigation schemes displaced rural populations and differentially favoured only a small proportion of the farming sector. Critics of the Green Revolution characterised it as favouring only well-off farmers and landholders. It was also described as a manifestation of Western capitalism that favoured multinational corporations. Indeed the 'Green Revolution' was coined as a counter to the 'Red' revolution that some in the West feared would sweep across the newly independent colonies. The investments in agricultural/rural development and food security were very much a part of the West's Cold War portfolio.

The break up of the Soviet Union brought an end to the Cold War and with it a shift in ODA emphasis. China was embarking on an economic path compatible with Western interests. The fear of mass starvation was receding and the risk that social upheaval could lead to major changes in geopolitical and economic alignments seemed to fade. In the 1990s policy makers became aware of the science behind human activity-induced climate change. More broadly, global attention turned to the condition of the environment as exemplified by the 1992 Rio Earth Summit. In some quarters modern agriculture was seen as a major contributor to environmental degradation, especially in developing countries (IAASTD 2009; Robertson 2012). The adoption of new Sustainable Development Goals in 2015 (United Nations 2015b) has, however, recognised the critical role of sustainable agriculture in reaching development objectives while conserving our environment.[4]

Likewise, as the abundance of starchy staples removed the primary cause of starvation – inadequate supply of calories – second order problems appeared, such as inadequate supply of vitamins and minerals in the diets of the poor and nutrition-related problems such as diabetes and cardiovascular disease. This is the human nutrition manifestation of Liebig's 'Law of the Minimum'[5] first articulated in plant nutrition: the growth potential of an organism is not determined by the overall availability of essential nutrients, but by that essential nutrient that is in shortest supply. Once that nutrient is in adequate supply, others take its place as the limiting factors.

This brief historical perspective touches on several themes that recur throughout this book. First is the importance of technological breakthroughs required for major gains in agricultural production and productivity. The impacts of technologies cannot be foreseen,

unintended consequences are inevitable, and inherently these are neither good nor bad. Second, policies should be viewed not only as determinants of food availability or scarcity, but also as means through which technologies may realise their full impact. Third, there is a tension among policies, technologies, and social values and norms. It is useful to tease apart very briefly some examples that illustrate these themes. Let's begin with nitrogen fertiliser.

## Technological innovation

Nitrogen (N) is first among equals of major essential plant nutrients, along with phosphorus and potassium (Ladha *et al*. 2016). It is a part of almost all structures and processes in all living things. Although it is abundant in the atmosphere, most organisms are incapable of directly using the atmospheric form of N. All animals obtain all of their nitrogen ultimately from plants or microbes. To maintain or increase crop yields, N must be added to the soil in some way, because there is almost never enough innate supply from soil to meet basic plant needs. Some microbes can transform N from the atmosphere into biologically useful forms and this can be taken up by plants. These microbes my live symbiotically within plant roots, as in legumes, or as free-living organisms in close proximity to crops such as rice but under quite specific low-oxygen conditions. Most commonly, though, farmers add N to the soil as some form of fertiliser. Until recently this was from animal waste, crop residues or periodic flooding of fields that brought in fresh nutrients. By the late 19th century there was widespread concern that natural sources of nitrogen for fertilisers, primarily mineral nitrate and guano deposits, could not keep pace with demand. This fed into concerns about the impending 'Malthusian trap' where famine and misery were a direct result of the divergence between the arithmetic growth rate of agricultural production and the geometric rate of population growth. Demand for food by ever-growing populations would inevitably outstrip supply.

Such predictions depend on the sometimes not-so-explicit assumption that key aspects of the future will be pretty much the same as those in the past. Over almost all of human history this was a safe assumption. Transportation in 1500 BCE was not all that different from transportation in 1500 CE, and communication was dependent on transportation. Disease and health were pretty much a matter of Divine will. And almost everybody stayed close to home. However, what was not readily obvious in the 18th and 19th centuries, but is clear today, is that the rate of technological change appears to be following the same pattern of exponential growth as human population growth. With the benefit of hindsight this is not a big surprise. New ideas and innovations produce 'offspring' – ideas and technologies – that, given a favourable environment, produce new generations of ideas and technologies. Moore's law describing the doubling of computing power roughly every 18 months is a well-known example of how feedback loops accelerate the rate of change.

The Haber–Bosch process used the newest technologies to generate enormous pressures, made possible by advances in metallurgy and catalytic chemistry, under which atmospheric nitrogen in the presence of methane (as natural gas or produced from coal) was converted into ammonia. This ammonia could be used directly as a fertiliser or used as a feedstock to produce a range of different nitrogen fertilisers. This led directly to abundant and inexpensive nitrogen fertilisers that have helped feed billions of people over the past century, thus at least postponing our Malthusian fate.

An interesting twist to the nitrogen fertiliser story is that a major impetus for creating ammonia was not only to produce fertilisers. Haber's initial work was driven in part, if not

wholly, to find a practical way to produce ammonia to meet Germany's need for explosives for their munitions industry (Erisman *et al*. 2008). So, the process that led to eliminating famine for millions not only contributed to the deaths of untold millions via warfare, it was intended to be used to kill countless people. The benefit to humans may well have been an unintended consequence.

## Policies, famines and technological revolutions

Most readers of this volume will be familiar with famines that led to the deaths of enormous numbers of people. Some of these were the result of a combination of gross mismanagement, genocide or outright cruelty, sometimes exacerbated by the weather or other environmental factors. These include those in the 1920s and 30s during collectivisation in Russia, the millions who died during Mao's Great Leap Forward beginning in 1959, and the Biafra famine in West Africa in the late 1960s.

Those famines with putative natural causes include the Irish potato famine of the 1840s and the Bengal famine of 1943. Potatoes had become a staple for much of the European population after their introduction from the New World in the 1500s. Late blight of potato, a serious disease caused by the mould-like *Phytophthora infestans*, arrived in Europe in the mid 1840s. It devastated the potato crops across the continent, but the impact was particularly severe in Ireland where the peasant population depended almost exclusively on potatoes for their sustenance. But it was not simply the potato disease that caused the famine: the rest of Europe also suffered devastating losses to their potato crops but did not experience as severe a famine. An important difference was that England's grain policies (the 'Corn Laws') imposed high tariffs on imported grain and artificially kept prices high so that even grain produced in Ireland was beyond the means of most of the rural population. Countless Irish perished in the midst of relative plenty.

The seizure of Burma from the British by Japan during World War II disrupted rice supplies for British troops and citizenry in Asia. Coincidentally, rice production in eastern India was reduced by a fungal disease. The resulting hoarding and redistribution of remaining rice supplies to British troops led to the starvation of millions in the Bengal region of India.

In both the cases of India and Ireland, while food production was severely reduced because of natural events, there were actually relatively abundant supplies of food available within reach of the populations. However, the governments had in place policies that mitigated against provision of the food to the starving populations. Outright gifts of food for famine relief were not considered appropriate for various reasons and the extremely poor rural people had no means to buy food.

Are all famines a result of policy failures? There certainly can be a case made for this in the modern world where deliveries of food to populations threatened with starvation can be made long before severe hunger sets in. There are now sophisticated early warning systems in place, global communications reach almost all regions where food shortages may occur, and the global community in general is more inclined to react swiftly to humanitarian crises. So, policies can also avert famine.

Entities such as the UN's World Food Program, government ODA and many private charitable organisations respond quickly to food shortages before they can become famines. These organisations are able to operate with reasonable efficiency within policy frameworks across many nations that facilitate the flow of information and food in a timely manner. This in itself is a significant policy contribution to food security.

What of policy–technology interactions? Like technologies on their own, experience argues that policy innovations create their own feedback loops. Significant policy contributions to food security may be those that resulted in investments in technological advances, infrastructure and inputs. The growth in food supplies from the interactions of the different investments was probably many times the potential impact of any single investment. The high-yielding modern varieties of rice and wheat depended on adequate water and fertiliser to express their potential. Large investments were made in irrigation and rural infrastructure that brought reliable water supplies and fertiliser to farms and resulted in major production increases. Policies around water and fertiliser pricing were developed to promote their use with the express purpose of increasing food production. Rural roads connected newly productive lands to much larger markets. Government guaranteed prices assured farmers of a predictable income and consumers of affordable food. Investments in improving crop productivity via breeding and agricultural practices pay off when the crops are grown in optimal environments; investments in improving the crop growth and market environments pay off when crops have the genetic potential to respond to improved conditions.

## Focus on crops, cereals, Asia and Africa

Three cereals – rice, wheat and maize – supply roughly 50% of human caloric intake. Within the major staple grains, most maize is raised for animal feed and is therefore mostly an indirect food source for people. Half of global wheat is produced in China and India, and it is the single most important source of protein. Almost all rice is consumed in developing countries (Awika 2011) and provides over 20% of human calories. If food security concerns should focus on developing countries and emerging economies – those areas with the most poverty and malnutrition – then wheat and rice can be very useful crops from which to draw specific examples.

A brutal, simplistic, but illustrative assessment of priorities could be: if the world fails to meet basic human needs in these major staple crops, any other success would be irrelevant because millions would starve. And, success in producing adequate supplies of the staple grains is a global victory for food security, even if there is failure in other aspects of agriculture. To some extent, this sums up the short-term accomplishments of the early Green Revolution. Starvation was averted and investments began to shift to other areas. But major investments are still required for proper nutrition, thriving populations and healthy environments. As the world undergoes major demographic changes from rural to urban, shifts in expectations from newly urban, wealthier and better-informed populations, and changing production potential of major food-producing regions, another major rework of agriculture is certainly called for. We are seeing not only major changes in how food is produced and by whom: the way food is marketed, who is buying increasingly internationally traded food, and how it is transported are having a growing important impact on what is grown and the kinds of food that are available and affordable to a very large proportion of our population.

If changes in global food security are measured as changes in numbers of hungry people and the ability of the poor to pay for enough food to meet their needs, then the most important places to track will be where the greatest concentrations of poor and recently poor live. Asia and Africa have over 5 billion of the world's estimated over 7 billion people. Most of the world's poor are also found in these regions. So any treatment of the impacts of technologies and policies on global food security should focus on these very high demand and potentially very high impact regions.

## Food production, food security and climate change

There is little doubt within the scientific community that global climate is changing and that much of this change is the result of human activities. Burning of fossil fuels, agricultural and industrial processes and deforestation all contribute to increased greenhouse gas concentrations in the atmosphere. Decreases in biodiversity through habitat destruction and over-exploitation of natural resources may reduce the resiliency of natural systems to respond to the temperature and precipitation changes that are occurring. Sorting through the possible impact of climate change in particular regions is extremely difficult because the uncertainty in the various models blurs what the specific impacts will be and where they will occur. Regardless, major changes in distributions of rainfall and favourable temperatures are certain to occur. Today's populations are still distributed based on legacy access to agricultural productivity of the past – not necessarily of the future. How the global community responds to climate change will certainly have an impact on the security, food and otherwise, of coming generations.

There is one major exception to the uncertainty surrounding the precise impact of climate change. And there is at least one obvious caveat that gives reason for some optimism. The exception is sea level rise. It is well established that global sea levels are already rising and all models predict this to continue throughout this century. The magnitude of the rise is uncertain, but that they will rise is not. This is important not only for the very large urban areas situated at current sea level, but also for the vast river deltas of Asia on which an enormous amount of the world's rice is grown. Serious flooding and seawater intrusion will increasingly threaten the gains in production these regions experienced in recent decades. To a degree there are genetic means to adapt rice plants to flooding and salt water. The extent to which these biological solutions will be deployed and the feasibility of major supporting infrastructure investments, such as dikes, pumps and canals, remains unknown.

The methods and timeframe over which new crop varieties are developed drive the caveat that new crop varieties may take climate changes in their stride. High-quality varietal improvement programs breed crops in environments that mimic the intended growing environment. As temperatures, for example, change over decades the selection of new varieties of necessity takes place under the 'new' environments. The rate of climate change (many decades) is generally slower than the rate of varietal development (less than a decade). As our predictions of changing climate become more precise, breeding for adaptation to future environments is becoming feasible. A far better understanding of plant genetics and our ability to precisely manipulate breeding environments, as we will see, should allow plant breeders to develop high-performing crop varieties for the future climate. Globally this is good news. However, implicit in this view is that food production will shift to more favourable areas as climate shifts. For individual farmers and many countries this is not necessarily good news at all.

Much more complex, unfortunately, is what happens in the larger agroecology. The impact of temperature changes on the distribution and behaviour of pollinators, pests, pathogens and the broader ecology is still largely unknown.

## Some foreshadowing

Recognising that many readers will not read every chapter, and without giving too much away, it should be helpful to highlight some of the key messages that will emerge from the

overall coverage of this book. A quick read of the introductory remarks for each section will reinforce these messages.

It is already clear that the ultimate impacts of technologies and policies will depend on how they interact. Monitoring of their impacts by relevant scientific and political bodies can identify and reinforce positive feedback loops and squelch negative loops. What will be needed is for the decision makers in both areas to be aware of the relevant undertakings in the other to better inform their decisions. A challenge, of course, is agreeing on what is a good outcome.

Readers will see many examples of different and competing values and objectives. Is it inevitable that they be cast as 'either/or' alternatives? How are differing objectives weighed when a choice must be made? What is the value of the quality of a human life in comparison to, for example, the costs of preserving biodiversity? How should costs be distributed across societies, among countries, and between the public and private sectors? How should the distribution of benefits be determined?

A striking and recurring theme is unintended consequences. Opponents of the use of genetic engineering and 'GMO' crops cite unknown, unintended consequences as a justification for their caution. The unspoken and demonstrably false assumption is that these consequences will be overwhelmingly negative. What should be obvious to all, though, is that essentially every intervention, be it technology or policy, will trigger a cascade of results only some of which will be the explicit and intended ones. Making sense of how these results move through and impact communities, economies and ecologies is a major challenge. Ultimately the answers to questions of what is a 'good' outcome, for whom, and compared with what alternatives will be determined within a political environment.

## Endnote

1 The FAO traces its origins to the International Institute for Agriculture founded in 1905. A useful timeline may be found at: http://www.fao.org/about/en/.

2 See https://en.wikipedia.org/wiki/An_Essay_on_the_Principle_of_Population for a concise summary of Malthus' landmark paper 'Essay on the principle of population as it affects the future improvement of society'.

3 For a summary of the first 40 years of the CGIAR see: https://cgspace.cgiar.org/bitstream/handle/10947/2761/cgiar40yrs_book_final_sept2012.pdf?sequence=1.

4 A very readable treatment of two contrasting views of mankind's future in mid-20th century is captured in *The Wizard and the Prophet: Two Remarkable Scientists and Their Dueling Visions to Shape Tomorrow's World* by Charles C. Mann (Knopf Publishing, New York, USA).

5 See https://en.wikipedia.org/wiki/Liebig%27s_law_of_the_minimum for an entry into this fascinating part of agricultural history.

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