# 1 The Basis for Food Security

## 1.1 Defining What Food Security Is and How Food Supply Chains Can Deliver It

This chapter will clarify many of the complex definitions of food security so that we can relate them to the food supply chain and food system. Our analysis will present the findings from research, agricultural field trials, and industrial case studies that have shaped the current food system. As previously described, food security is often a difficult attribute to describe adequately because it is the sum of many aspects of our lives. Food security is concerned not only with the immediate supply of protein and energy, but also the sustainable supply of a healthy diet that promotes well-being. While the immediate requirement for protein and energy is critical, security will also include what we experience as accessibility, affordability, and availability of foods when we consume them as meals and our diet.[1] Indeed, an important viewpoint put forward in this book is that food security should consider all of us as consumers rather than recipients of food. While this is a descriptive point, it is important to understand that food security is not only an issue of quantity, it has become an issue that is increasingly identified by quality of life and safety attributes that are delivered to consumers.



*Global Food Security and Supply*, First Edition. Wayne Martindale.

In such a context, the food supply chain provides all the criteria necessary for food security, and this means the components of the supply chain must operate efficiently. Defining the components of supply and consumption is an important first step in understanding food supply chain efficiency. The food supply chain operations that make food security a possible goal are dependent on the production of ingredients and raw materials from agricultural operations and the development of food products by manufacturers and processors. A critical function of the food supply chain that is extremely variable and the focus of much attention because of the relationship to consumers is that of the distributor, wholesaler and retailer, who make sure that food is presented to the consumer. Thus, these agricultural, manufacturing, retailing and consumption aspects of the food supply chain can be presented as a series of four functions that are shown in Figure 1.1. The food supply chain functions will be discussed and investigated in further chapters, but the role of Figure 1.1 is to explain food supply with elements of simplicity that are the key to us developing ideas in the further chapters of this book.

Naturally, the simplicity presented here is fine for explanation of principles, but when this supply chain model is applied to populations, it becomes very complex due to several other attributes associated with the impacts, services, and capital of businesses and consumers that require consideration. The supply chain shown is easy to understand, but projecting it to populations and millions of consumers means it becomes potentially impossible to visualise. The sheer scale of supply functions in populations and the variance of inputs and outputs into food supply chains globally result in the need to consider the model presented in Figure 1.1 as a food system. Scientific and sociological research has provided evidence that shows how the development of food supply chains can result in the establishing of an understanding of what makes a food system sustainable.[2] These ideas will be developed, but an

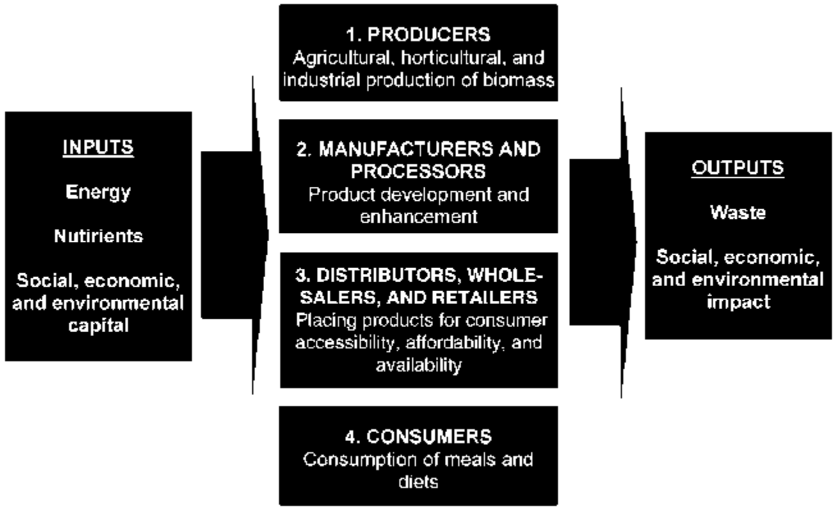


**Figure 1.1. The food supply chain functions and food system. There are four functions to the supply chain scenario presented here: producers; manufacturers and processors, distributors, wholesalers, and retailers; and consumers. Inputs and outputs can be measured as a balance or LCA function at each function. This is a relatively simple model, but it becomes complex when applied to populations and several supply chains.**

understanding of different types of inputs and outputs from the food system is central to the ideas put forward and critical in determining our perspective on food security.

An important consideration for each part of a food supply chain as a producer; manufacturer and processor; retailer, distributor, and wholesaler; and a consumer is to consider where products are being made and where they are being used. Understanding these two parts of the supply chains is critical, and it has been traditionally defined by supply and demand functions that determine what consumer trends are evident. This view of supply chains has been established for centuries and as we will see it has now developed to consider other value aspects of goods at the end of the twenty-first century. These values are associated with social and environmental impacts, as well as economic wealth creation, and they have increasingly become coupled with criticality of supply for specific resources. That is, the supply and demand functions of supply chains must increasingly be affiliated with assessment of security of supply. This is true for most manufactured goods, it always has been, but new pressures have emerged to make an understanding of the 'push or pull' components in supply chains. These include rapidly changing abundance of resources, geopolitical structures, price variability, price volatility, environmental impact, and health impact. Assessments of these attributes together can provide important world views on the risk of limited supply when they are blended with the consumer trends. Food supply chains provide the data concerned with material flows that enable the assessment of risk and uncertainty of ingredient and food supply. Thus, understanding where foods come from and where they are used allow us to project trends in consumption and allow us to develop strategies that deliver resilience in response to volatility and geo-political change.

Identifying the attributes of supply chains that can determine trends and criticality of supply are well characterised and have been for a significant period of time now. For example, the thought-provoking 'Limits to Growth' reports identified population growth, availability of natural resources, pollution, and capital investment in food supply chains as critical points in delivering sustainable global food supply.[3] Whereas security assessment of supply chains is well developed for minerals and metals, it is perhaps less so for food products. The key players in providing this assessment of security are those involved in the supply chain functions, that is, the producers, manufacturers, retailers, and consumers. Understanding price variability and volatility of resources is crucial to developing trends and strategies for dealing with risk and uncertainty associated with food supply. The time scales that are used can change our perspective on sustainability because many assessments will consider data from a time series of 5 years even though we might consider projections of decades into the future most important. Price data can be used for longer periods, and we should always consider the value of using longer term time series that are greater than a 5-year historical record.[4] It is notable to observe the recent price spikes in food globally that augmented the current food security debate, and the value of using 5-, 10-, 20-, 50-, or 100-year historical price series will provide different projections for security.[5] Thus, a consideration of the attributes we use to develop trends is just as critical as the time series we utilise to develop food security projections.[6] The caveat placed by this study and book is that this cannot be done without considering the food supply chain due to the supply chain being both the provider for trend data and a source of innovation that enables the delivery of food products that consumers demand.

Indeed, the need for organisations and businesses to rank the materials they utilise in terms of the risk associated with supply has become more important since the food price spikes of 2005–2008, otherwise called the 'perfect storm' scenario.[7] The perfect storm was a convergence of increased demand for livestock products and a diversification of agricultural biomass into liquid biofuels. This created price volatility and uncertain supply. In a similar way, the trade of steel used for industrial infrastructure and rare earth metals used in electronic goods experienced extreme price volatility at the same time. The price hikes have focused our thinking around security with regard to our considerations of sustainability and the amount of resource reserves that are available to food supply chains.[8] That is, how much genetic biodiversity, useful land, minerals, metals, and fossil fuels are available to produce food products. The current security debate has not only considered quantity of food, but it has begun to consider the quality attributes of food with nutrition that delivers well-being. That is, reductions in quality blended with increased production of biomass, ingredients, and food products may not provide the benefits we think because of the impact on energy consumption during manufacture and health impact after consumption.

The consideration of closed loop economies has emerged from security crises, these are systems that eradicate or reduce waste from supply chains so that everything used to produce a product remains within the supply chain or linked with other supply chains. Closed-loop thinking is different for food products because it is usually consumed and cannot be re-eaten. However, food waste within supply chains is of critical importance to future security and sustainable supply. Furthermore, nutrients manufactured into food products can be recycled within the food system to support the production of biomass. Indeed, the production of composts and manures for agricultural systems is likely to have been our first experience of recycling materials several thousand years ago. We do increasingly know more detail about the environmental and social impacts of food products due to increased access to data that are either open sourced or peer reviewed. These show the emission factors and mass-flows for food ingredients and products. Thus, for the first time, we can now identify criticality points in food supply because of the economic impetus to do so. This can be integrated with measures of sustainability for the first time historically, and it is being done by food supply chains that will survive the 'perfect storms' of the future.

## 1.2 The Convergence of Food Security Research, Economics, and Policy

Specific analytical methods are often employed to measure inputs and assess the impact of outputs from the food system that traditionally identified economic and mass flows through the food system. This approach used to overlook social and environmental services, and this proved limiting for anyone who required a measure of current and future performance of the food system. Therefore, if we are to project future food security and sustainability taking a purely economic view based on production of foods, it would be a very fragile representation of the food system. The limits to such economic assessments were explored in a 1997 *Nature* paper by Professor Robert Costanza and colleagues, who estimated the ecosystem service worth of the globe to be two to three times that of the economic wealth.[9] This paper changed the way we think about natural systems and the sustainability of the global food system; it has also extended our views on how food security could be delivered. The global policy-making environment established by the World Commission on Environment and Development report 'Our Common Future' 10 years before demonstrated distinct convergence of views from policy and research on sustainable natural resources.[10] The 'Our Common Future' report established the United Nations (UN) Conference for Environment and Development or 'Earth Summit' and a set of targets for the new millennium known as Agenda 21. The paper by Costanza and colleagues provided an assessment of integrating the goals of sustainable development with the financial risk if we were not to meet sustainability targets that were increasingly being developed by policy-makers, and understanding this risk was critical to the future of humankind. The Costanza and colleagues' *Nature* paper essentially stated that we should be very aware that inaction on sustainable development could be associated with trillions of dollars of risk and gave the following description in its opening statement:

> *The services of ecological systems and the natural capital stocks that produce them are critical to the functioning of*

*the Earth's life-support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet.*

This 1997 paper changed how we measured and assessed the food system, and it also related inaction on food security to very clear financial risks. This was important because the Costanza paper demonstrated that the growth of economic capital was clearly influenced by both social and natural capital.

## 1.3 The Millennium Development Goals (MDGs)

The convergence of research and policy research in food security resulted in the bold establishment of the Millennium Development Goals (MDGs), which is an international programme developed from approaches established in the 'Our Common Future' report in 1987. While the international landscape of agreement, conference, and commissions can seem unpractical, the dialogue they have established has changed from one of describing problems to one of achieving and meeting specific goals, which are shown in Figure 1.2.

The first MDG aims 'to eradicate poverty', and it uses assessments of economic, social, and natural capital to identify how food insecurity can be alleviated in the world. The progress to the target is recorded, and this achieves an establishment of accountability. Thus, the MDG's do provide the important starting point for our study of food security and supply utilising the ecosystem service approach. We are approaching the point where we know whether we can achieve the eight MDGs laid down for the global community in September 2000 during the Millennium Summit of the UN. This was one of the largest ever gatherings of heads of state, and they marked the new millennium by adopting the UN Millennium Declaration.[11] This was endorsed by 189 countries, and it established a

1. Eradicating extreme poverty and hunger

2. Achieving universal primary education
3. Promoting gender equality and empowering women

4. Reducing child mortality rates
5. Improving maternal health
6. Combating HIV/AIDS, malaria, and other diseases

7. Ensuring environmental sustainability
8. Developing a global partnership for development

**Figure 1.2. The MDGs as described by the UN; the MDG 1, 4, 5, and 6 relate directly to issues of diet and sustainable nutrition for well-being.**
***Source*: Adapted from *Road map toward the implementation of the United Nations Millennium Declaration*. New York: United Nations, 2002. United Nations General Assembly Document A56/326.**

roadmap for achieving the goals to be reached by 2015.[12] Roadmaps have become important illustrative tools for policy development, which put forward agreed targets and suggested routes to obtaining them. The MDGs are important because they have provided targets and a new round of questioning the actual competencies of international efforts.[13]

The MDGs are important as they provide a standardised measure of progress towards food security that have been agreed by the members of the UN. These both provide a means to compare progress across nations, and it gives a form of consensus on what is required to provide food security. The MDG Target of halving those people experiencing hunger is reported as 'within reach' in the UN MDG Report 2013[14] An important consideration of the MDGs is the spatial variation in attaining them, with sub-Saharan Africa and South Asia presenting the most acute areas for food security concern by being most at risk.

The UN Food and Agriculture Organisation (FAO) reports progress in reaching the MDGs, and they have stated the following in 2013 for achieving an MDG1 Target of halving the number undernourished people since 1990:[15]

*The [revised results imply that the] Millennium Development Goal (MDG) target of halving the prevalence of undernourishment in the developing world by 2015 is within reach, if appropriate actions are taken to reverse the slowdown since 2007/08.*

This Target is one of 21, and it is part of the first Goal, and it is fraught with controversy because of the period between 2005 and 2008, which saw a new phase of development in the global food system that exposed fragility in supply. This was due to the demand for agricultural products from national economies that had globalised since the 1990s and most notably resulted in food price increases in 2010 that had significant impact on the world food system.[16] Changes in food price and affordability have severe impacts on the number of people experiencing hunger, and the price spikes of 2010 resulted in hundreds of millions of people experience poverty or extreme poverty.[17] Globalisation of the food supply chain shown in Figure 1.1, produced changes in consumption, tastes and society that had dramatic impact of where agricultural commodities were traded and what they used for.[18,19] As such, the MDGs begin to describe the complexity of what food security is because they not only highlight the supply of resources to eradicate poverty and hunger, but also consider access to, safety of and education regarding the use of natural resources. The 2012 FAO report, 'The State of Food Insecurity in the World', which is published annually states the following.[20]

*The State of Food Insecurity in the World 2012 presents new estimates of the number and proportion of undernourished people going back to 1990, defined in terms of the distribution of dietary energy supply. With almost 870* *million people chronically undernourished in 2010–12, the number of hungry people in the world remains unacceptably high.*

The FAO reported that the vast majority of these people live in developing countries, where about 850 million people, or in some cases close to 15% of the individual nation state populations, are estimated to be undernourished.

## 1.4 Measuring Hunger in a Changing World to Establish Security

The Global Hunger Index (GHI) provides a descriptor of how we assess hunger, and it is published by the International Food Policy Research Institute (IFPRI), Concern Worldwide, and Welthungerhilfe.[21] The 2012 GHI shows that progress in reducing the proportion of hungry people in the world is slow and hunger on a global scale remains 'serious'. Twenty countries still have levels of hunger that are 'alarming' or 'extremely alarming'. South Asia and sub-Saharan Africa continue to have the highest levels of hunger. The 2012 GHI is the seventh year that IFPRI has calculated it, and the country averages represent variable data, so those countries classified as having 'moderate' or 'serious' hunger can have specific areas where the situation is 'alarming' or 'extremely alarming'. This has important implications for mapping food supply and security because the use of maps can effectively convey and describe variability in large data sets that include the social, cultural, and ecosystem attributes used to describe hunger.[22,23]

The development of the GHI and other measures associated with food supply and security that take into account spatial variation within regions is likely to be an important future development. The resolution of food security data spatially is an important component of future food policy and the deployment of actions that tackle food security. Naturally, population census data and the reporting of food supply statistics are critical to any measure of spatial variation, and the coverage of agricultural, food industry, and population census globally will limit these actions.[24,25]

Spatial variation of food security is not the only reason why measuring hunger is not straightforward. It can be described in many ways; as with food security, it is multidimensional. The GHI combines three equally weighted indicators that are broadly agreed upon across many organisations dealing with it and combines them as a single index. The three indicators that are combined are now described:

1. **Undernourishment:** The proportion of undernourished people as a percentage of the population (reflecting the share of the population with insufficient caloric intake).
2. **Child underweight:** The proportion of children younger than age five who are underweight (i.e., have low weight for their age, reflecting wasting, stunted growth, or both), which is one indicator of child undernutrition.
3. **Child mortality:** The mortality rate of children younger than age five (partially reflecting the fatality of inadequate caloric intake and unhealthy environments).

The GHI aims to provide insight into the nutrition situation of not only the population as a whole, but also children who are a physiologically vulnerable group where a lack of nutrients leads to a high risk of illness, poor physical and cognitive development, and death. The GHI ranks countries on a 100-point scale in which zero is the best score (no hunger) and 100 the worst, although neither of these extremes is reached in practice.

'Hunger' is understood to refer to the discomfort associated with lack of food and the FAO defines food deprivation or 'undernourishment' specifically as the consumption of fewer than 1,800 kcal a day. This is determined to be the minimum that most people require to live a healthy and productive life and anything under this would be considered undernutrition. The FAO considers the composition of a population by age and sex to calculate its average minimum energy requirement, which varies by country.

The FAO defines food insecurity as the following.

> *A situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life. It may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution, or inadequate use of food at the household level. Food insecurity, poor conditions of health and sanitation, and inappropriate care and feeding practices are the major causes of poor nutritional status. Food insecurity may be chronic, seasonal or transitory.*

Thus, even undernutrition is more than a consideration of the consumption of calories because it includes deficiencies in energy, protein, or essential vitamins and minerals. Undernutrition can be the result of inadequate intake of the quality or quantity of food and includes poor bioavailabity of nutrients because of disease or reduced quality of food consumed. Overnutrition represents the problems of unbalanced diets that are largely caused by the consumption of too many calories and are often associated with poor micronutrient quality of diets.

## 1.5 The Undernutrition and Overnutrition Gap

Figure 1.3, demonstrates the gap between undernutrition and overnutrition globally. The FAO data shown are derived from national agricultural and food industry

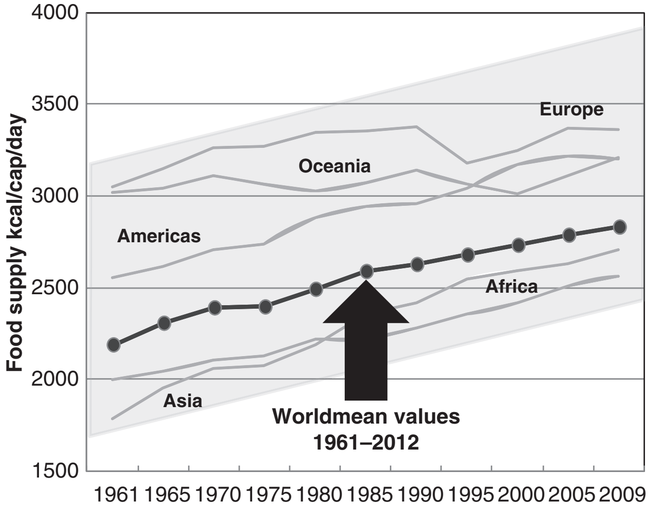


**Figure 1.3. The undernutrition gap demonstrated for global mean calorific supply (FAOSTAT data).**
***Source*: These data were adapted from FAO. FAOSTAT (2009). Food supply, crops, primary equivalent data set. http://faostat .fao.org/ (accessed 22 April 2014).**

census. The figure shows the average supply of calories to individuals has increased year on year since 1961, but there have been clear inequalities in how supply is distributed globally. Asian and African regions have consistently been below this average and are cited in IFPRI and FAO reports that measure undernourishment as areas of most concern. European, American, and Oceanic (principally Australasian in this instance) are Calorie sufficient.

The Brandt report defined these spatial inequalities and it was published in 1980 by an independent commission Chaired by Willy Brandt, chancellor of Germany from 1969 to 1974.[26] At its most basic, it provided an understanding of drastic differences in the economic development for both the North and South hemispheres of the world. The Brandt report is important because it raised the issue of the 'standard of living' differences that exist along the global North–South divide, and there should therefore be a large transfer of supporting resources from developed to developing countries. It most certainly did not foresee the extent of globalisation and the emergence of the impact large economies, such as China, would have on the world food system. In many respects, it presents the prior world view of globalisation and even though the inequalities it identified do still exist, as shown in Figure 1.3, the impact of globalisation was not foreseen. Indeed, the type of analysis led by Brandt has been reanalysed and perhaps most emphasised by Professor Jared Diamond in his book *Guns, Germs and Steel*.[27] These analyses firmly place the role of limitations placed on the food system by land and climate to be considered in delivering food security because they will influence the capacity to supply food. While technologies will alleviate these limitations, the access to them may be again limited or controlled by trade.

## 1.6 The Supply Chain and Nutrition Gaps

We can increasingly see that delivering food security is not only a case of producing ingredients and foods, there is an absolute requirement for highly efficient supply chains that deliver safe and nutritious food to consumers. While supply chain functions can be viewed simply as a series of four components shown in Figure 1.1, they quickly become complex at the scale of populations. Complexity in supply becomes apparent when the number of consumers, suppliers and ingredients used increase. Figure 1.3, demonstrates the impact of these principles on current global calorie supply. The world food supply of protein actually approaches 80 g for each person per day, as reported by FAO statistics in 2009, which is considered to be sufficient for most of the global population, at least a third of this can be from cereals.[28] Advice from FAO and WHO state 0.66 g of protein per kg of body weight is sufficient for a healthy diet that maintains health.

The FAO and WHO figure now combine a 1973 protein recommendation that relied on a limited number of short-term and longer-term nitrogen balance studies with a later 1985 study to derive the protein requirement of adults. Some of these studies were designed to identify a requirement and others to test the safe level (0.58 g protein/kg per day). Taken together in the 1985 report, they were interpreted as indicating a mean requirement of 0.6 g protein/kg per day, with a coefficient of variation estimated to be 12.5% in a typical population. This resulted in a safe protein intake recommendation of 0.75 g/kg per day; that is, a value at 2SD above the average requirement (0.66 g protein/kg per day), which would provide for the needs of nearly all individuals (97.5%) within a target population.

Human metabolism regulates protein consumption to about 15% of total intake of a meal, and this is a much stronger relationship than for fat and carbohydrate.[29] This will be returned to later, but there is strong evidence to suggest that the sustainability of healthy diets can be measured by protein content. Indeed, protein intake leverages itself against fat and sugar consumption in that when protein intake is low, consumption of fat and sugar may increase in order to reach the 15% level of protein intake.[30] As previously discussed, the average global protein supply hides large variations, with the protein supplied to an average European each day being 102 g, some 35 g more than a typical African. This variation describes the range of protein deficiency and oversufficiency, and it can also hide significant changes in the protein balance of diets shown in Figure 1.4. The protein supplied from cereal crops in Europe has declined since 1961, whereas during the same period, it has increased for the Asian region, where there are severe food security impacts, as highlighted by the GHI assessment. This transition identifies how regions can increase protein supply and change protein consumption dynamics globally. The average Asian

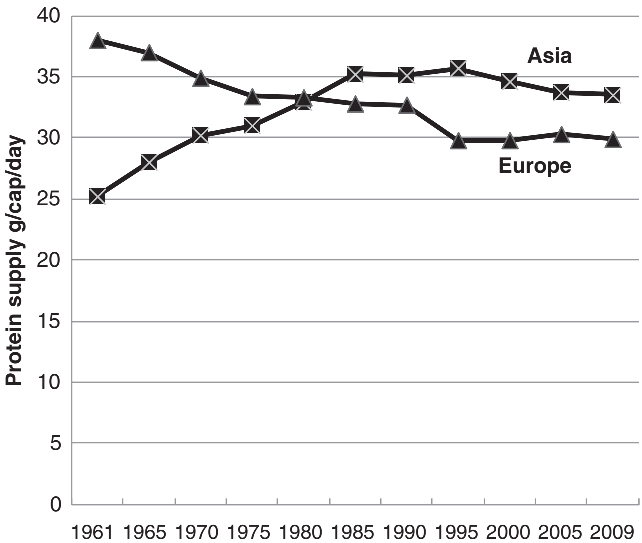


**Figure 1.4. Protein supply from cereal crops in Asia and Europe1961–2010.**
***Source*: These data were adapted from FAO. FAOSTAT (2009). Food supply, crops, primary equivalent data set. http://faostat.fao.org/ (accessed 22 April 2014).**

citizen will be supplied with some 30 g less protein than a European citizen on a daily basis, but more of the protein in an Asian diet is from cereals than a European one.

This is important because dependency on cereals for balanced protein and nutrition depends on efficient production, and it has provided an important target for improving health. For example, the development of golden rice varieties with enhanced carotene content has been developed by large agricultural companies that have included Ciba Geigy and Monsanto and the resulting golden rice Humanitarian Board.[31,32] The controversy surrounding the genetic modification technologies used to produce these varieties has met with resistance even though there is a clear nutritional benefit to consuming biofortified crops, such as golden rice. There are very clear indications that the pro-vitamin A activity of enhanced carotenoids also improve the bioavailability of other micronutrients, such as iron.[33]

## 1.7 The Relationship between Food Security and Biology

What has changed during the course of progress to the MDG Target for halving hunger is that the focus for tackling food security has become far broader than tackling agricultural limitations. Even though it is clear that improving agricultural production does alleviate pressure on the food system with respect to supplying a nutritious diet, there are many other components of the food supply chain that will restrict access to food if they are not considered. It has become clear that the requirements for economic growth and social protection to be embedded in policies that are sensitive to supplying a nutritious diet are critical in delivering food security.[7]

An understanding of how sciences have influenced changes in food security policy is as necessary as appreciating the role of social, political, and economic change. With this in mind, the application of bioscience to agriculture has improved food security for billions of people, and it was the focus of alleviating hunger in the twentieth century. The Green Revolution of the 1960s and 1970s saw crop yields per hectare rise dramatically because of the application of crop breeding programmes that were targeted for specific global regions. Reassessments of cropping and grazing management globally provided a way of identifying where crop breeding, engineering, and management programmes could be applied to increase the yield of biomass per hectare of land. These approaches at the time were effectively led internationally by Dr Norman Borlaug, who was awarded the Nobel Peace Prize in 1970 and established the World Food Prize in 1987 for research excellence applied to the whole food system.

This was a time when it was clear what needed to be done because the risks of not doing anything to alleviate food insecurity were being made all too clear by research presenting the limits of natural resources, such as that of Professor Paul Ehrlich's population time bomb ideas put forward at the end of the 1960s.[34] Dr Norman Borlaug recognised the potential for tailoring crop varieties for specific global regions and particularly arid regions where water limitation and hunger were likely to be chronic problems. The agricultural system was critical to alleviating the threat of famine that Ehrlich's book laid out to the world, and Borlaug offered an option for overcoming the limits imposed by the agricultural systems of that time. By developing crop varieties that would enable crop yield to remove the scourge of hunger from the lives of millions of people, he demonstrated field agronomy had a critical role to play. He stated the following:

*Civilization as it is known today could not have evolved, nor can it survive, without an adequate food supply.*

Borlaug's approach to alleviating the limits of food supply began in 1944, when he participated in the Rockefeller Foundation's wheat improvement programme in Mexico as a research scientist working on wheat production problems that were limiting wheat cultivation. This developed disease- and climate-resistant varieties, but also trained scientists to develop new methods of managing crops by a process known as agricultural extension. The field basis for extending agricultural research to production has been critical to developing agricultural systems that can alleviate hunger. New wheat varieties with improved yield potential and improved crop management practices transformed agricultural production in Mexico during the 1940s and 1950s and later in Asia and Latin America, sparking what today is known as the 'Green Revolution'. This approach has led to science and crop breeding saving millions of lives, with the World Food Prize Foundation stating the following, which demonstrates the value of extending the actions taken by crop scientists to the saving of human life by alleviating hunger.

> *Because of his [Dr Norman Borlaug's] achievements to prevent hunger, famine and misery around the world, it is said that Dr. Borlaug has "saved more lives than any other person who has ever lived."*[35]

What Borlaug did was to show a clear way of alleviating food supply limits by improving agricultural productivity. The rule base for doing this was relatively simple in that agriculture should be fit-for-purpose in specific environments that have different climate, soils and needs. If we consider the words of Dr Daniel Hillel, who was awarded the 2012 World Food Prize, in his book *Out of the Earth*, it is clear that these things often overlooked:

> *All terrestrial life depends on soil and water. So commonplace and seemingly abundant are these elements that we tend to treat them contemptuously.*[36]

The World Food Prize does provide an indicator of change with regard to tackling many of the challenges the food system places before us. Tackling the food insecurity that has limited the ability of humankind to ease conflict and the unsustainable use of natural resources entails using multidisciplinary approaches. The World Food Prize reflects this with the Laureates being from the policy, agronomy, biotechnology, and human health arenas.[35] Development of new crop varieties and methods of growing crops feature strongly in the list of Laureates, along with those that are focused on the policy and political development of efficient supply chains. This demonstrates the duality of achieving food security in that the limitation of the supply function can be alleviated by efficient agricultural production that taps into genetic resources of crops and livestock. However, security can be achieved only if social and political will support supply functions from the farm to the consumer. What has become apparent with the World Food Prize is the need to reevaluate what Borlaug achieved by improving farm efficiencies because it is clear that production and yield of crop varieties and livestock breeds have improved globally, so what do we do now to maintain efficiency?

This is apparent if we consider yield improvement of major crops since the 1960s, where yield increases between 2% and 10% year-on-year have been observed for crops that are crucial to the production of ingredients and feed. These types of data set also raise extremely important considerations of weather and climate because from year to year, changes in temperature and water availability have significant impacts. The year-on-year yield increase of wheat grain between 1961 and 2012 for the United Kingdom and world has been 0.8% and 1.9%, respectively (FAOSTAT data). Figure 1.5a,b shows that these data sets hide variation in yield percentage change year-on-year during this 52-year period. Understanding this variation is important because it enables the implementation of structured adaptive management that can both deal with the uncertainty associated with weather and the trends associated with environment change. A notable recent study of this issue of long term changes and trends is that of Schlenker and Roberts (2009), who used long-term data sets to demonstrate that when the corn, soybean and cotton crops of the USA experience temperatures of above 29°C, yield decreases are seen and can be projected with confidence limits.[37]

Schlenker and Roberts (2009) suggest their research shows limited historical adaptation of seed varieties or management practices to warmer temperatures because they also accounted for changes in farm practice, such as water storage in response to increased temperature. They predict average yields to decrease by 30–46% before the

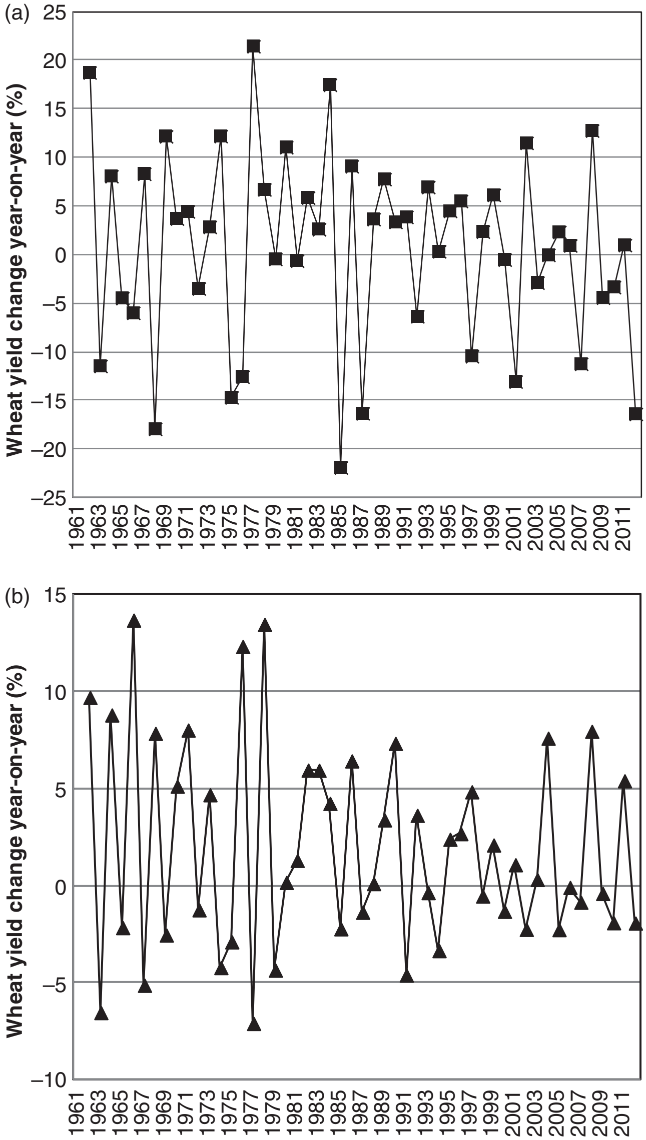


**Figure 1.5. (a) Changes in the yield of wheat grain year on year in the United Kingdom 1961–2012. (b) Changes in the yield of wheat grain year on year globally 1961–2012.**
***Source*: These data were adapted from FAO. FAOSTAT (2012). Production, crops data set. http://faostat.fao.org/ (accessed 22 April 2014)**

end of the century under the slowest global warming scenario and decrease by 63–82% under the most rapid warming scenario. Naturally, this has extreme implications for the food system and offers a target for plant breeders to select for crops that can tolerate extreme changes in temperature and water availability. Their research also highlights the requirement to work with long-term data sets when dealing with natural systems and the issues of food security. Working with long-term data should also implement adaptive management to account for changes in the environment and climate as they become apparent.[38] Adaptive modelling integrates well with the food system because records regarding biomass yield and production are often long term.[39] Indeed, the use of adaptive modelling is a key part of what we might consider integrated practices in agriculture and other parts of the food supply chain.

The recognition of the role crop breeding and agronomic technologies must have on yield improvements has enabled continued yield improvements, but there is a requirement for adaptive modelling and actions to be in place to account for environment change and global warming. Significant yield gaps do still remain if we take a global view of crop yields, and these are not closed by the development of technologies alone, they must be adaptive and respond to changes in environment, markets, and consumers.[40] The yield gap principle is presented in Figure 1.6 for wheat, rice, and maize, whereby the maximal national yield is compared with the global mean yield value of a crop and the resulting gap between them is considered the 'yield gap'.

As with most global and national production statistics, an understanding of variability in data must be emphasised with the fact that they will simplify complex supply chains. Regarding these cautions, the yield gap scenarios do still provide useful insights into what might be achievable and how maximum yields globally might be reached.

Cropping systems are the ultimate start of the food supply chain because photosynthetic biomass initially

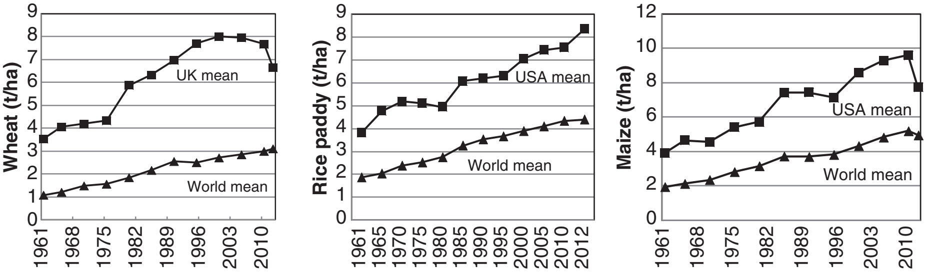


**Figure 1.6. Global yield gaps for wheat, rice, and maize. These yield gaps can be represented as the percentage gap between the greatest and world average yield of biomass. The percentage yield gap can be simply understood as an indicator for reaching the capacity for maximum yield of biomass. For example, the percentage yield gaps for wheat, maize, and rice shown are 53%, 36%, and 47% for the year 2012.**
***Source*: These data were adapted from FAO. FAOSTAT (2012). Production, crops data set. http://faostat.fao.org/ (accessed 22 April 2014).**

captures solar energy that is consumed by humans either directly or via livestock, or transformed via microbial fermentation onto food materials. Notable production systems based on microbial fermentations will be discussed in the following chapter because they offer potential to alleviating nutrition gaps globally, but Figure 1.6 describes crop yield gaps for three of the major food crops globally.

The limitation of defining production inefficiencies by crop yield gaps alone is fraught with difficulties because agriculture provides only the beginning of the food supply chain. The supply of food to consumers is dependant on all of the functions shown in our initial food supply chain model shown in Figure 1.1. For example, it is now apparent that the impact of waste and spoilage within supply chains is having a critical effect on getting food to consumers.[7,41] Furthermore, the role of processors and manufacturers in developing nutritious foods that are efficiently preserved does have a central role in the supply chain.[42] Indeed, the central place the processor and manufacturer occupies in supply chains between farmers producing ingredients and retailers who present food products to consumers is a critical one. Indeed, the case for adaptive modelling across food supply chains has not been used creatively and offers great opportunity to closing yield gaps and providing a more secure food system. The quantification of determinants of crop and livestock yield, such as different management practices, breeding programmes, and new technologies are rarely specifically defined in measures, such as Total Factor Productivity (TFP) and Life Cycle assessment (LCA). While TFP and LCA offer important methods for traceable analysis of products there is a requirement for assessment of respective components of crop and livestock yield that identify gaps in both the application of technology and the development of effective management that will help to close them.

This requires the assessment of both quantitative data concerned with the measurement of processes such as growing crops and qualitative data that describe how people feel about the implementation of new methods of production or development of new products. The application of biotechnology demonstrates the need to not only understand the process of developing solutions using technologies but also to engage users of technology, in this case consumers of food in the most appropriate way. The food industry as a whole understands this relationship because it delivers safe and wholesome food that has a very clear hedonistic purpose associated with it. That is, the food industry works with mixed research methods, both quantitative and qualitative at all times and this is well characterised. If we like how food tastes and performs when cooking and eating it, we are likely to consume it. Measuring this principle of hedonism is not as straightforward as it may seem, and it is explored with case studies and data later, but it is the basis for developing and managing sensory panels in the food sector. Sensory panels are groups of consumers who regularly test and assess food products;

the data from these panels are used to compare food products in terms of value, quality, taste, and performance.

## 1.8 The Relationship between Food Security and Biotechnology

The emergence of biotechnologies that can transfer specific genes between crops and livestock and thus transform traits that will improve production in the way that Borlaug did for cereals has revolutionised agriculture. The 2013 World Food Prize reflects this new biotechnological dialogue that accompanies the programmes that will tackle food insecurity in the world because it has been awarded to researchers whose work will impact on both the quantity and quality of biomass produced from farms. Dr Marc Van Montagu's research established the role of the *Agrobacterium* spp. plasmid stable vector for introducing genes into crop plants but this work crucially needed the involvement of crop technology companies. The 2013 Prize was co-awarded to Dr Mary-Dell Chilton and Dr Robert Fraley of the Syngenta and Monsanto group of companies. This addition to the Laureates helps us to define a change in reassessing Borlaug's legacy because the application of directed gene transfer and biotechnology is not only set to improve crop and livestock yield but improve nutritional quality.

An important example of quality improvement has been the establishment of agrifortification and biofortification; both result in the nutritional enhancement of biomass. Agrifortification achieves this by utilising mineral additions to food ingredients within the supply chain. Biofortification is a more stable process in that the nutritional enhancement is achieved by using the crop or livestock metabolism to improve nutritional aspects. This can be achieved by gene transfer, such as Agrobacterium-mediated transfer of genes or by traditional selection of varieties and breeds to achieve the desired response. Perhaps the most publicised example of biofortification mediated by gene transfer has been the development of the golden rice, but the principle of biofortification offers much hope in alleviating the so-called hidden hungers.[43] Golden rice was developed by the Ciba Geigy company to tackle a specific nutritional problem that has hampered the nutritional benefits of consuming cereals.[44] That is, cereals can provide a good source of energy and protein, but they are often less nutrient dense in the case of minor nutrients, such as minerals and vitamins. Vitamin A in rice was a significant challenge because it was principally consumed where agrifortification was not possible and cereals are a major component of diet. Vitamin A deficiency is known to increase the prevalence of a blindness associated with decreased consumption of foods containing the precursors of vitamin A.[45] Golden rice varieties are biofortified using genes that enabled rice seeds to accumulate vitamin A precursors and thus alleviate deficiency in diets where rice is the major food staple.[46]

An important aspect of developing new crop varieties is to understand how consumers cook and utilise them so that we can be sure that they meet the sensory and textural targets of being included into recipes and meals. This aspect of new crop variety development has been often overlooked, and the case study that golden rice provides is of critical importance to the market acceptance by consumers.[47] While elucidating the attributes associated with consumer use and market entry have traditionally been the interest of commercial functions of the supply chain, they are increasingly important to all aspects of supply and development, including the development of initial research and development concepts for new crop varieties. The concern consumers have about genetically engineered crop varieties has been established since the late 1990s, and recent food security issues have alleviated many of these concerns by considering the safety of products and their role in the whole supply chain; this includes consumer use and acceptance.[48] The development of consumer panel data in these types of situation where new ingredients and products are being developed has an important role to play that is likely to be more apparent in the future development of genetically engineered crops.

Indeed, the crop biotechnology sector has defined the safety of crops at all points in their development, and notable studies show no difference between genetically modified and non-genetically modified crops apart from the specific gene or genes introduced to the crop.[49] Genetically modified wheat varieties that provide significant opportunities to the bakery industry with regard to protein quality and micronutrition have been shown by research to show no difference to non-genetically modified varieties other than the introduced gene, but their introduction to the food chain is hampered by what can be considered consumer and qualitative issues.[50,51] A notable example of a biotechnology company developing programmes of assessment to communicate the total value of genetically modified or industrially produced organisms is the Novozymes A/S company, which is headquartered in Denmark. Novozymes A/S has used LCA to develop assessments for its products, and these methods assess the benefit of using industrial biotechnology on grounds of sustainability criteria.[52] Such a model of customer engagement and supply chain assessment can provide important insights into how biotechnologies within the food supply chain might be accepted by consumers globally.

## 1.9 Genetic Diversity of Agricultural Crops and Livestock

Tackling the concerns of introducing new properties and performances to agricultural products raises the whole issue of genetic diversity in the crops and animals we utilise for producing food. Whereas the diversity of product taste and texture has often been introduced by processing and manufacturing new ingredients and foods so that they provide desired performance in recipes, such approaches have not been used in farming. Naturally, the opportunities to do so are limited and were defined by Professor Jack Harlan nearly half a century ago when Borlaug was beginning to formulate the route of the first Green Revolution. The drivers for this first Green Revolution were genetic diversity, and Harlan's reconsideration of the origins of crops and livestock were important in this context. Harlan redeveloped existing ideas on biodiversity and agriculture in that he established that the world food system depends on a limited number of plant species and these evolved in three areas of agriculture that include the Near East, Mesoamerica and North East Asia.[53]

Previous analyses considered between 8 and 12 centres of origin, which Harlan called non-centres because of the variation in genetic diversity within regions from which crops and livestock first developed, were not strictly defined as centres because they were diffuse. Regardless of the actual centres or areas of origin of agriculture, it is clear that the genetic stock of agricultural systems is limited because of the relatively few species utilised and the narrowly defined geographic regions they first developed from. Whereas the number of crops that supply most calories globally number under 10 species (mainly cereals), the number of plant species utilised for taste, fragrance, and medicine is likely to reach several thousand, with some estimates around 50 000 species. These metrics provide an illustration of the complexity in relating crop and livestock diversity to specific centres of origin or species, because it is highly likely that agriculture evolved with complex relationships within landscapes. Thus, while it is useful to think of centres of origin for agriculture, we must consider the genetic diversity that is used for the whole food system in geographic regions, including taste, fragrances, and medicines.

## 1.10 Trade Agreements and the Development of Agricultural Supply

If we are to consider the efficiency of the agricultural production system, which is the producer of food and animal feed ingredients, then the development of trade agreements globally have without a doubt been most influential in enabling new technologies and management. In Europe, the development of the Common Agricultural Policy (CAP) has dominated the agricultural sector since the late 1950s (Figure 1.7).

The development of the CAP provides an important case study in the development of a sustainable agricultural system. This is because several reforms or adaptive changes

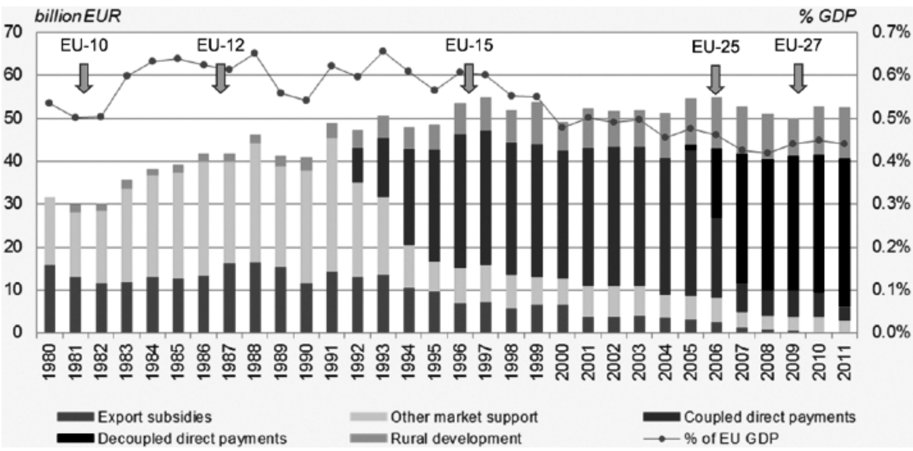


**Figure 1.7. CAP expenditure and reform path budget evolution; while overall (unadjusted) budget has increased, it is worth noting the changes in distribution of the main measures (specifically the increase in Direct Aids and Rural Development), as well as the significant increase in number of farm businesses, together with the enlargement of the EU.**
***Source:*** **The graph is from the DG Agriculture and Rural Development, Agricultural Policy Analysis and Perspectives Unit © European Union (2013). http://ec.europa.eu/agriculture/cap-post-2013/graphs/index_en.htm (accessed 22 April 2014). (For a colour version, please see the colour plate section.)**

have been made from initially aiming to develop stable markets by price support to developing sustainable landscapes and a resilient food system. In the 1980s, CAP expenditure was targeted to price support through market mechanisms, such as intervention (when world prices were low) and export subsidies. Market subsidies resulted in agricultural surplus, and in 1992, there was reform of the CAP, where market mechanisms were reduced and replaced by direct payments. Direct payments were 'producer support' not 'price support' for agricultural products. Further reform has increased spending on rural development measures that enhance landscapes and ecosystem services.

Figure 1.7 also shows the impact of the 2003 reform where direct payments were shifted to decoupled payments where CAP payments are no longer paid per hectare or per animal but made in terms of farming function. This is related to sustainability and environmental criteria associated with farming, as well as the functions of biomass production for the food system. Spending on rural development has developed during this period, showing an important consideration for the food production to be integrated into the social and community well-being of society. CAP spending has stabilised despite the successive enlargements and represents 0.44% of the European Union gross domestic product (GDP). However, the CAP expenditure as share of the EU budget has decreased over the past 25 years, from almost 75% to 44% in 2011. This decrease has taken place despite the successive EU enlargements and the downward path of CAP cost in the EU is due mainly to the CAP reforms.

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