The future of food and farming

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ABSTRACT

The UK Government Chief Scientist takes stock of the enormous challenges facing governments and citizens in balancing the competing pressures and demands on the global food system, not least in providing an adequate and sustainable nutrition for a rapidly-expanding population against the background of climate change. There are grounds for optimism in scientific and technical innovation, and in a growing consensus that global poverty is unacceptable and has to be ended. But the decisions ahead are difficult, and bold action is required to achieve the sustainable and fair food system the world so desperately needs.

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For the latter part of the twentieth century, in the Western world, we have come to take the availability and affordability of food for granted. Indeed, in most developed countries, rather than worrying about the poorest people starving, obesity has become the modern food-related epidemic. But despite this apparent abundance of food, worldwide hunger still remains widespread and many aspects of the food system are unsustainable. Over the next 20–40 years, the food system will face significant further challenges as world population grows and critical resources such as water, energy and land become increasingly scarce, at the same time as we address and adapt to climate change. Deciding how to balance the competing pressures and demands on the global food system will be a major task for policy makers. The two year Government Office for Science Foresight project explored the increasing pressures on the global food system between now and 2050, bringing together evidence and expertise from a wide range of disciplines across the natural and social sciences and involving several hundred experts and stakeholders from around the world, to identify choices and to assess what might enable or inhibit future change. Their findings, published in the report 'The Future of Food and Farming: Challenges and Choices for Global Sustainability' launched on the 25 January 2011, highlight the decisions that policy makers need to take today, and in the years ahead, to ensure that a global population rising to nine billion or more can be fed sustainably and equitably.

One of the biggest factors driving our need to change will, in the short to medium term, be population growth. Based on the United Nations Population Divisions projections, today's population of about 7 billion is likely to rise to around eight billion by 2030 and to over nine billion by 2050 (United Nations 2009).

Most of the population increases will occur in low-income countries – Africa's population is projected to double from one billion to two billion by 2050 for instance (United Nations 2009). These population increases will also combine with other transformational changes, as rising numbers of people move from rural areas to cities that will need to be serviced with food, water and energy. Already a billion are hungry, 0.9 billion lacking access to clean water, and 1.4 billion without efficient electricity. Up to 192 million more people will be living in urban coastal floodplains in Africa and Asia by 2060, through natural population growth or rural-urban migration (Foresight, 2011d). Half the world's population now live in urban rather than rural areas, a figure that is projected to rise to 60% by 2030. It is estimated that there will be 26 cities with more than 10 million inhabitants in 2025, up from 19 today. Five of these new 'megacities' will be in Asia. The pace and scale of urbanisation will affect global food consumption. As many people are likely to be wealthier the demand for a more varied high quality diet, including increased dairy and meat consumption, will have major implications for the competition between resources (water, land and energy etc.) for food production and sustainability.

These increasing demands on our food system will add pressures on a system that is already failing in two major ways, both of which demand decisive action. Firstly, the global food system fails to feed the current world population appropriately. Nearly 1 billion people are hungry, and another billion are thought to suffer from 'hidden hunger', in which important micronutrients (such as vitamins and minerals) are missing from

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their diet. In contrast, a billion people over-consume substantially, spawning a new public health epidemic involving chronic conditions such as type 2 diabetes and cardiovascular disease.

Secondly, many aspects of food production are currently unsustainable and the need to reduce greenhouse gas emissions and to adapt to climate change will become imperative over the coming decades. There are already widespread problems with land degradation as a result of soil loss from erosion, loss of soil fertility, salinisation and other pressures. Other challenges include: rates of water extraction from aquifers for irrigation are exceeding rates of replenishment in many places; over-fishing is a widespread concern; and there is heavy reliance of fossil fuel-derived energy for producing nitrogen fertilisers and pesticides. In addition, food production systems frequently emit significant quantities of greenhouse gases and release other pollutants that accumulate in the environment. Without change, the global food system will continue to degrade the environment and compromise the world's capacity to produce food in the future.

Any one of these factors would present substantial challenges for food security, but together they constitute a major threat. Our food system needs to change more radically in the coming decades than it did during the Industrial and the Green Revolutions. Many poor farmers orientate their livelihoods towards meeting their basic needs, particularly food, and with insufficient income, have little money to invest in increasing the productivity or sustainability of their production systems (IAASTD 2008). Substantial innovation will be needed, not only to increase production to the scale required, but to achieve this sustainably in a world where there is growing competition for resources, particularly land, water and energy. Sustainable intensification means simultaneously raising yields, increasing the efficiency with which inputs are used and reducing the negative environmental effects of food production. It requires economic and social changes to recognise the multiple outputs required of land managers, farmers and other food producers, and a redirection of research to address a more complex set of goals than just increasing yield.

This means there is a strong case for reversing the low priority that has been given to research on agriculture, fisheries and the food system in most countries – not just in biotechnology, including GM, but in more neglected subjects such as agricultural ecology, soil preservation and agronomy. For example, preserving multiple varieties, land races, rare breeds and closely related wild relatives of domesticated species will be important to keep a genetic bank of variation that can be used to select novel traits in the future; advances in soil science and related fields offer the prospect of understanding better how crop production is constrained and how we can improve the way we manage soils to preserve their ecosystem functions, improve output, reduce pollutant run-off and cut greenhouse gas emissions. Revolutionary advances such as developing perennial grain crops, introducing nitrogen fixation into non-legume crops and reengineering photosynthetic pathways for different plants were also all identified as important areas for study, but translating new science and knowledge into applications in the field takes time and is not certain. As some of these new technologies will take up to 40 years to make a contribution in the field, we need to make the investment now if we are to be ready to meet future needs.

A good example of a specific problem where more research can help is the challenge presented for the livestock sector with increasing demand for dairy and meat products. A significant amount of meat is obtained from 'grain-fed' (primarily wheat, barley, maize and soya) livestock (particularly poultry and pigs), and diets high in this type of food have a large resource footprint. The highest proportion of grain-fed meat is found in US diets, where the per capita requirement of grain is four times that of a vegetarian diet. However, there is great variation in the impact of different meat production systems, and the largest growth (particularly in Asia) is predicted in pigs and poultry, where resource efficiency can be relatively high. There are also exceptions to the generalisation that only the relatively wealthy have high meat-based diets. Many poor pastoral communities have diets based on livestock but sell high-value livestock products to buy lower-cost staple foods, and addressing their needs is critical to the reduction of hunger. Overall, the global cattle population has been predicted to increase by around 70%, from 1.5 billion in 2000 to about 2.6 billion by 2050, and the global goat and sheep population by nearly 60%, from 1.7 billion to about 2.7 billion over the same period. While acknowledging that these predictions are inherently uncertain, increases in the consumption of meat at this scale will have major implications for resource competition and sustainability. Research to find ways of reducing greenhouse gas emissions (and other negative externalities on the environment) from livestock production is a priority, while ensuring that livestock growth opportunities do not marginalize smallholder producers and other poor people who depend on livestock for their livelihoods (IAASTD 2008), along with a better understanding of what drives such dietary changes and how to discourage over-consumption and further growth.

The yield gap is normally considered to be the difference between actual yields achieved and the maximum possible yield given local soil and climatic conditions. Increasing food production using existing technologies is sometimes referred to as 'closing the yield gap'. Yield here usually refers to output per hectare, which assumes that land is the scarcest factor. However, farming systems vary greatly in terms of land availability, which means that maximising output per hectare may not always be the rational economic strategy. Equally, even where land is scarce, closing the yield gap may not be desirable if, for example, pushing yield to the maximum produces other unwanted outcomes, such as eutrophication of surface water (Pretty *et al* 2003), greater emissions of greenhouse gases or declines in wildlife (Foresight 2011a). Equally, it may not be financially worthwhile to increase production if competing supplies are available at lower prices. Achieving maximum yield from farmland, fisheries, livestock or aquaculture is constrained both by the genetic potential of the plants and animals involved and by management of the biophysical environment in which they grow or are reared. In a world of perfect information, producers would choose how much to invest in added inputs or intensification of management, given the expected returns and the revenues they can hope to receive from alternative use of these resources. In practice, all farmers live in a world of imperfect information, in which there are significant costs to acquiring information and they are subject to considerable uncertainty as regards rainfall, pest attacks, crop prices and ill health. This is especially the case for those in low-income countries, where there are also few options to insure against risk, not helped by poorly developed infrastructure, whether in roads, storage and markets, or in input and services. Conflict and political turmoil will also discourage farmers from making long-term investments in raising farm productivity. These factors keep yields low (Foresight 2011b).

The majority of the world's poorest people live on small farms and there are many existing technologies and interventions that would bring substantial gains to smallholder agriculture in sub-Saharan Africa, and elsewhere. Applying existing knowledge and technology has been estimated to increase average yields two to three fold in many parts of Africa, and two fold in the Russian Federation. Similarly, global productivity in aquaculture typically could, with limited changes to inputs, be raised by around 40% (Bostock *et al* 2010). Revitalising education or 'extension' services to increase the skills and knowledge base of food producers (often women) is critical to achieving sustainable increases in productivity in both low-income and high income countries (Pretty 2003), helping to increase producers' knowledge about best practice and to expand the social capital within and between institutions and communities in the food supply chain. Strengthening farmer associations is a vital means to addressing the range of challenges faced by farmers, whether for issues of the environment, market access or innovation. In Uganda, women have organised into groups to process and sell cassava. In Nigeria, aquaculture entrepreneurs have emerged to focus on raising and selling fish, while others concentrate on producing and selling feed. In Kenya, the extension system encourages farmers to form common interest groups for business activities (Foresight 2011c). Access to modern information communication technology (ICT), often as simple as mobile phones, in rural communities could also offer substantial potential for the dissemination of knowledge and good practice. National prioritization of the needs of resource-poor farmers may be more important in the future as scientific and agricultural technology spillovers from developed countries that are adapted by developing countries may be less available (Alston 2006). Farmers in high-income countries are demanding high-technology inputs that are often not as relevant for subsistence agriculture (such as precision farming technology or other capital-intensive methods). As well as differences in value-adding processes to serve consumer demands, differences in farm production technologies are emerging to serve the evolving agribusiness demands for farm products with specific attributes for particular food, feed, energy, medical, or industrial applications (Pardey *et al* 2006).

At the same time as putting food production back on the agenda however, it's important that we recognise that it can't be looked at in separation from the issues of water availability, energy supply and climate change. Greenhouse gas emissions from the food system constitute 12–14% of all emissions and are likely to increase substantially in the decades ahead. Livestock and nitrogenous fertiliser are major sources of emissions of the greenhouse gases methane and nitrous oxide. Agriculture uses 4% of global fossil fuels, of which about 50% is required for producing fertilizers. Agriculture already consumes 70% of the total global water withdrawn from the rivers and aquifers available to humankind (FAO 2006). There is a clear case for making agriculture and food production a central issue in future negotiations on global emission reduction, not least at the forthcoming COP17 discussions to take place in Durban in December 2011. The features unique to this sector will however need to be taken into account, in particular the possible effects on efforts to reduce world hunger and ethical issues concerning which geographical and economic groups should bear the costs of mitigation.

But as well as thinking about how we can help agriculture adapt to climate change, we should also be considering how agriculture can be used to mitigate climate change. Increasingly thoughts are turning to how, in the future, terrestrial and aquatic ecosystems used in food production will need to be managed to achieve multiple goals. The current World Bank/ FAO initiative highlights the need for 'Climate-Smart' agriculture, which promotes agricultural production systems that either reduces the level of green house gas production per unit product, or actually sequesters carbon dioxide in the production system. Improving current cropping and livestock systems to develop these new sustainable farming systems, will require using better technologies which produce less GHG emissions, and building on local and traditional knowledge. For example, the Nhambita community carbon project in Mozambique has offset 24,117 tons of carbon dioxide equivalent by helping farmers to adopt better agroforestry techniques (FAO 2010). Long term carbon capture on farmland through agroforestry may also provide other benefits such as reducing soil erosion and producing renewable fuels and animal feed. Similarly in Peru, there have been a number of initiatives to help increase milk production in poor rural areas through improved pasture management and breeding programmes. These initiatives have helped increase milk production by 25% per cow. This means that farmers are able to keep smaller, more efficient herds, which increases their incomes and reduces greenhouse gas emissions too (FAO 2010). Similarly, gains could also be achieved through appropriate management of aquatic and aquaculture habitats and the value of mangroves, seagrass beds and saltmarshes for sequestration needs to be recognised more fully and measures taken for their protection and restoration.

In the UK, there are also some real opportunities to improve food production in a low carbon way. The recently launched multi-partner Global Food Security programme promoting better co-ordination and coherence across public funded agri-food research is exploring multi-disciplinary approaches combining economic, environmental and social evidence to consider how to improve input-use efficiency (nitrogen, and water) and reduce the amount of food waste within the food system, while minimising adverse effects on the environment. The Technology Strategy Board (TSB) in collaboration with Defra, BBSRC and Scottish Government is investing nearly £16 million in 29 projects that will help to secure the sustainable supply of protein such as meat, fish and animal feed. The Greenhouse Gas Action Plan (GHGAP) sets out how the agriculture industry in England will tackle climate change by reducing greenhouse gas emissions by three million tonnes of CO2 equivalent per year from 2018–2022. These initiatives on various aspects of climate-smart agriculture will help us not only understand the full consequences of the very complex and context specific impacts on greenhouse gas budgets of different practices, but also help us to develop the potential of agriculture in reducing atmospheric carbon dioxide.

Agriculture also has a vital role to play in maintaining biodiversity. The food system relies on a variety of services that are provided without cost by nature (ecosystem services) but the way we produce food may negatively affect the environment and therefore harm the same ecosystem services it relies upon, or affect those that benefit other sectors. Indeed food production takes up more land and has a greater impact on marine and freshwater ecosystems than any other human activity – this can only increase as demands for food increase over the next 40 years. Until recently policies in conservation and in food security were largely developed in isolation. However, given their interdependence, there are both economic and non-economic arguments for why biodiversity should be considered in decision-making regarding our food system. This will however create some difficult tradeoffs including: How intensively can we farm the land while still looking after wildlife? Who pays the cost of protecting bio-diversity? This last question is particularly difficult as some of the most threatened and diverse habitats on earth exist in very low-income countries, where many rural poor depend on local bio-diversity for their livelihoods. There are strong ethical arguments against imposing the costs of protecting biodiversity on those least able to pay them and the Foresight report recommends that this is a key area where international policy needs to act, ensuring that countries receive benefits in return for safeguarding or providing global ecosystem goods. At the same time however, it is clear that we need to firm up the evidence behind what constitutes wildlife friendly farming and how it potentially benefits bio-diversity. While there is a very large literature on wildlife friendly farming and the numerous ways in which biodiversity can be encouraged on productive land, there is still debate about the effectiveness of schemes aiming to encourage this approach. There needs to be a more analytical and evidence based approach to establish what works best.

The global food system will face enormous challenges between now and 2050 – indeed as great as any it has confronted in the past. Food production and the food system must assume a much higher priority in political agendas across the world and we must be prepared for change on an unprecedented scale. But although the challenges are enormous, the Foresight report does point to real grounds for optimism. Innovation in the natural and social sciences continue to offer new solutions and understanding; and there is growing consensus that global poverty is unacceptable and has to be ended. But the decisions ahead are difficult. They will require bold actions by politicians, business leaders and researchers, as well as engagement and support by individual citizens everywhere if we are to achieve the sustainable and fair food system the world so desperately needs.

About the author

Sir John Beddington CMG FRS was appointed as Government Chief Scientific Adviser (GCSA) on 1 January 2008. Since being in post, the GCSA has led on providing scientific advice to Government during the 2009 swine flu outbreak and the 2010 volcanic ash incident. The GCSA has also been responsible for increasing the scientific capacity across Whitehall by encouraging all major departments of state to recruit a Chief Scientific Adviser.

Throughout 2008 and 2009 Sir John raised the concept of the "*Perfect Storm*" of food, energy and water security in the context of climate change, gaining considerable media attention and raising this as a priority in the UK and internationally.

Prior to his appointment as GCSA, he was Professor of Applied Population Biology and headed the main departments of environmental science and technology at Imperial College. His main research interests are the application of biological and economic analysis to problems of Natural Resource Management.

Sir John has previously been advisor to a number of UK Government departments including the Foreign and Commonwealth Office, the Department for Environment, Food and Rural Affairs, the Ministry of Defence and the Cabinet Office. He has also advised several Governments and international bodies including the Australian, New Zealand and US Governments, the European Commission, the United Nations Environment Programme and Food and Agriculture Organisation.

He was, for six years, a member of the Natural Environment Research Council. In June 1997 he was awarded the Heidelberg Award for Environmental Excellence, in 2001 he became a Fellow of the Royal Society. In 2004 he was awarded the Companion of the Order of St Michael and St George by Her Majesty the Queen and in June 2010 was awarded a knighthood in the Queen's Birthday Honours.

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