# Food for thought

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During the past 250 y, the world has been gripped by periodic bouts of pessimism about our ability to feed ourselves. The first was prompted by Malthus' (1) famous 1798 *Essay on the Principle of Population* and the realization of the power of exponential population growth. The economic transformation of the industrial revolution postponed the crisis although concern erupted again in the mid-20th century as populations boomed in low-income countries. However, the development of new crop varieties and agronomic practices that constituted the Green Revolution radically increased food production in the 1960s and 1970s. Indeed, until a few years ago, the cost of feeding ourselves in real terms has been at a historical low. Now food security has again rocketed up the political agenda, and there is widespread concern about the volume of food production and its sustainability and resilience. This has been driven by a sudden increase in food price volatility, but also by strong growth in demand, especially from the emerging economies. Are food security concerns justified, and can and should something be done about them? Quantitative analyses by Tilman et al. (2) and Foley et al. (3) provide much-needed rigor in this important policy area.

The production and availability of food, as well as people's access to it, are affected by a large set of biophysical, economic, social, and political factors, which interact in complex ways to determine what we eat. Tilman et al. cut through this complexity to estimate what future demand-side pressures may be by statistically extrapolating present-day trends (2). The calories of food produced today in the poorest countries are approximately 2,000 to 3,000 kcal·d$^{-1}$ per person, which, after waste and food fed to livestock are taken into account, is considerably below the minimum thought to constitute a healthy diet. In the richest countries, 8,000 to 9,000 kcal·d$^{-1}$ per person are produced, much more than anyone could consume. Some of this excess is exported (including to the very poorest countries as food aid), but a very large proportion is fed to livestock and so is consumed indirectly by humans. The relationship between GDP and calorie production is remarkably tight, allowing likely pressures on the food system to be estimated based on assumptions about population and economic growth. Making reasonable assumptions about these trends, Tilman et al. (2) estimate that demand-side pressures will increase by approximately 100% by midcentury.

Is this increase in demand-side pressures inevitable? Although population growth is responsible for a sizeable fraction of this 100%, much is a result of the workings of what economists call Bennett's Law: as people become wealthier, they switch from simple starchy plant-dominated diets to a more varied food input that includes a range of vegetables, fruit, dairy products, and especially meat.* The food types consumed by wealthy people tend to require more resources to produce, and much could be done to reduce demand-side pressures if the rich world chose to eat less profligately. This need not necessarily mean becoming vegetarian, as Foley et al. and others have argued (3, 4); quite subtle changes in diet, for example, from red meat to white meat, can have large effects on the total calories and protein agriculture has to produce. Another way to lower demand-side pressures is to reduce food waste: approximately 30% to 40% of food is wasted, in low-income countries typically on the farm and in the food distribution system, and in the rich world largely in the home and food-service sector (5). Reducing food waste requires investment in the food system and in food literacy. A sophisticated discussion within civil society on issues such as demand and waste is needed to empower individuals to make informed choices about what they eat, and also to enable politicians to make difficult decisions involving food.

**Tilman et al. put numbers on the challenges faced by the food system.**

In addition to these demand-side pressures, the coming decades are likely to see increasing supply-side stress. Growing and richer populations will lead to greater competition for water and energy, increasing the input costs to food production (5). By 2050, there is a high probability that climate change will be having negative effects on food production, most likely through higher frequencies of droughts, floods, and other extreme events. The need for food production to play its part in mitigation, as well to adapt to climate change, may affect productivity.

## Response to Price Signals

One response to these demand- and supply-side challenges is to argue that food prices will increase and that this will stimulate production and moderate demand: the "hidden hand" of the market will automatically adjust the food system, and there is nothing for policy makers to worry about. There will be important responses to price signals, but there are many reasons not to rely on them alone, such as (*i*) the presence of time lags and capital constraints, (*ii*) the link between food and hunger, and (*iii*) the critical importance of food production to environmental sustainability.

There are natural time lags in agricultural responses to higher prices associated with the march of the seasons, but, perhaps more importantly, increasing food production requires human capital—the skills base needed to produce more food—as well as the economic capital available to the farmer to purchase seeds, fertilizer, and other inputs. The farmer also needs market access and the physical infrastructure to transport food efficiently. Higher prices will stimulate investment, but low-income countries in particular, from which much of the increase in food production has to come, have economies ill-equipped to meet this challenge in the short or medium term. Enabling investment to allow the food system to respond to price signals will be critical to meet the demand-side challenges Tilman et al. identify (2). For decades, investment in agriculture and food production was seen as a poor way to stimulate development. This is changing with a growing recognition that it has the triple benefit of stimulating rural economies, producing food where it is needed, and often preferentially helping relatively disadvantaged sections of society (including women, who dominate agricultural production in Africa). There are real success stories from low-income countries such as Ghana and Malawi, which have made major

Author contributions: H.C.J.G. wrote the paper.

The author declares no conflict of interest.

See companion article on page 20260.

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*Bruinsma J, FAO Expert Meeting on How to Feed the World in 2050, June 24–26, 2009, Rome.

strides in food production; however, how best to help more poorly performing countries is far from clear.

Increasing prices will reduce demand, but in a complex way, because food is not any other commodity. People literally have to eat to stay alive, so, as prices increase, an increasing fraction of poor people's incomes will be spent on food. However, between 0.75 and 1 billion people today do not have sufficient economic access to food, and even though populations in the future are likely to be wealthier on average, significant increases in food prices will hinder or reverse progress in reducing hunger (6). Thus, if we do nothing, economic forces may prevent demand from increasing as high as Tilman et al. expect (2), but chiefly because people are forced to remain in food poverty—something most people would agree is unethical and would pose grave risks for global political security.

## A More Sustainable Food System

A further reason to intervene in the food system is that it is plays a very major part in many of the gravest environmental threats facing the earth—loss of biodiversity, freshwater depletion, release of nitrogen and other pollutants, and greenhouse gas emissions. Tilman et al. (2) offer unique insights into how these externalities may be reduced while enough food is produced to meet projected demand. Again by using a statistical approach based on past country-level data, they ask how projected demand for food could be met assuming current trends in increased production continue and by a combination of (*i*) changing soil fertility (in particular as regards the use of nitrogen fertilizer), (*ii*) bringing more land into agriculture, and (*iii*) closing the yield gap, i.e., transferring technology to low-income countries such that they do as well as rich countries with comparable soils and climate. Many strategies meet projected demand, but they have very different effects on the environment. An option that has particularly positive environmental outcomes is based on land sparing, whereby existing technology is used to raise yields on current farmland while minimizing the land converted to agriculture. Although the necessary intensification can increase direct greenhouse gas emissions—although there are many ways to reduce this—these are dwarfed by the amounts avoided as a result of land conversion.

A number of recent studies have emphasized the importance of minimizing land conversion to limit greenhouse gas emissions (7). Foley et al. (3) also point out that cleared tropical forest typically makes poor agriculture land, although it does boost rural incomes, emphasizing the importance of finding other ways to support local livelihoods. There is a debate in conservation circles about whether biodiversity is best supported by farming less intensively (i.e., land sharing) or increasing yields on farmland to allow more uncultivated areas (i.e., land sparing). New data help make the case very convincingly for land sparing in tropical forested areas (8), although this may not be the case where the farmed landscape more closely resembles natural ecosystems (e.g., grasslands). There is also legitimate concern about land use governance and whether land sparing can be made to work in the long term (9).

The importance of spreading best practice identified by Tilman et al. (2) does not mean that investment in generating new knowledge is not required. There has been a recent deceleration in yield growths, possibly a function of decreased investment in research and development during a time of historically low food prices (10). Research is needed to maintain, let alone increase, production in the setting of evolving weeds, pests, and pathogens, as well as to meet the challenges of global change. The major crops that have received the most attention from plant breeders cannot be grown in many of the poorest regions in the arid tropics, and the application of modern science to these neglected species might have dramatic effects on yields (11). Similar arguments apply to neglected livestock species. Equally important is research into reducing the cost of existing technologies so that they might be taken up more easily in low-income countries.

Producing more food with less effects on the environment requires a radical shift in thinking by the agricultural and environmental communities. The goal for agronomists and plant and animal breeders is not now simply to increase yields but to optimize across a much more complex set of objectives, with a particular emphasis on increasing input efficiency and reducing harmful outputs. Innovation in areas such as precision agriculture, soil science, and climate-smart agriculture are urgently required to make what has been called sustainable intensification a reality. In addition, it will be critical to align market incentives to promote more sustainable food production, i.e., to internalize the costs (or benefits) of the negative (or positive) externalities. For the environmental community, a major challenge is to accept the inevitable loss of some biodiversity that feeding 9 to 10 billion people will entail and to work to develop integrated land use policies that minimize this harm.

The existence of the demographic transition—the fact that human populations modulate fertility as they become more secure—offers hope that a Malthusian catastrophe is not inevitable; that the resource demands the human population places on the planet may asymptote and even decrease. However, it is far from certain that this will happen without radical change to the way humanity interacts with the earth system. Tilman et al. (2) put numbers on the challenges faced by the food system, which should act as a call to immediate action, for if we fail on food, we fail on everything.


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