Malthus foiled again and again

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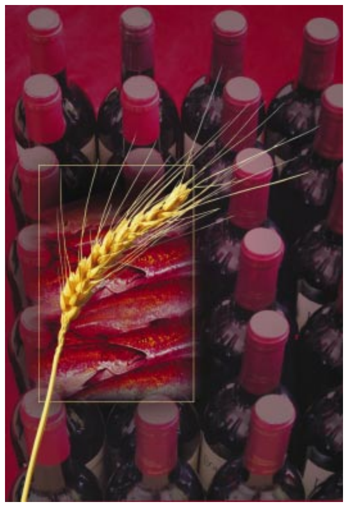
Throughout history, increasing population has driven the need to increase agricultural efficiency, so averting successive 'malthusian' disasters. In the twentieth century, the application of scientific knowledge to agriculture yielded tremendous dividends, enabling cereal yields to increase threefold since 1950. But with the world's population projected to reach nine billion by the middle of this century, new ways must be found to increase yields while preserving natural habitats and biodiversity.

Ever since the Reverend Thomas Malthus published *An Essay on the Principle of Population* in 1798 there has been concern over the twin problems of population and food[1]. Malthus, at least in his first edition, foresaw a human population always hungry and therefore malnourished. To be fair to Malthus, in later editions he did back-track on this apocalyptic view of the future of humanity, but he did receive the ultimate accolade — the incorporation of his name into the English language, with 'malthusian' now a recognized adjective.



At the time Malthus wrote and lived, famine was common in Europe. The French revolution in 1789 resulted from harvest failures and a consequent steep rise in the price of bread. The amount of land that was farmed was determined by how much wheat could be harvested during the three- to four-week harvesting period by one person with a scythe. The development of agricultural engineering led quickly to horse-drawn rotary harvesters that increased the amount of wheat that could be harvested, and farms grew as a result. Current agricultural technology enables one person to be fed from the food grown on no more than 2,000 square metres[2]. In Malthus's time it was nearer 20,000 square metres.

An increasing population drove the need to increase agricultural efficiency even further. In the middle of the nineteenth century, Leibig and others established the mineral content of plants and thus the chemicals needed to provide for good crop growth. Although the world population at the time of the French revolution was about one billion[2], the twin effects of engineering and fertilizer development enabled a doubling by the middle of the nineteenth century. Sources of fertilizer at that time were either deposits of guano (seabird droppings) or potassium nitrate (saltpetre) and by the end of the century many of these reserves had been fully exploited. Concerns grew that a burgeoning world population would once again be plunged into malthusian disaster.

A century of change

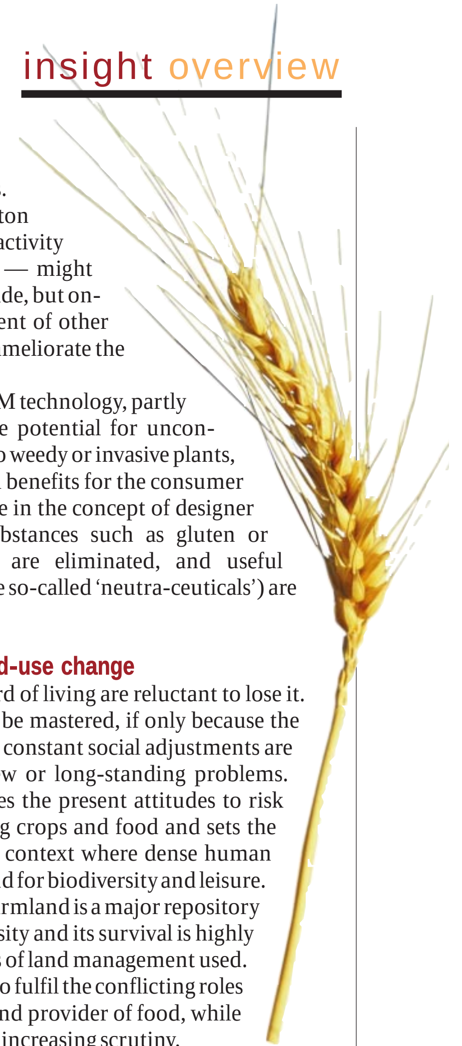
Salvation came from one of the few beneficial offshoots of the First World War: the development of the Haber–Bosch process in which atmospheric nitrogen was fixed and used to manufacture ammonia[2]. The Haber process was a product of the explosives industry (ammonia is used to make dynamite), but the immediate consequence was that humanity no longer had to rely on finite natural resources of nitrogenous fertilizer. Even coupling the Haber process to renewable energy sources has the potential to provide unlimited supplies of nitrogenous fertilizer — global output of fixed nitrogen from the chemical industry currently exceeds that of the biological nitrogen cycle. But overuse has its disadvantages, including the pollution of waterways, lakes and seas with nitrate, the encouragement of toxic algal blooms and the deterioration of water supplies[3].

The twentieth century was the era of plant breeding and genetics. The introduction of the concept of 'hybrid vigour' by Schull in 1900 stabilized US corn production[4]. For the first time the genetic base of crop production could be controlled and easily adjusted to accommodate the differing climates found in the continental United States. A century later, however, this process has led to the predominance of monocultures of limited genetic variability and increased vulnerability to the threat of disease. Malthusian crisis was averted once again with the 'Green Revolution' of the 1950s, by the introduction of dwarfing genes into rice and wheat[4]. Cereal yield over the past half century has increased threefold, allowing the human population to reach six billion.

No room for complacency

The application of scientific knowledge to agriculture has yielded extraordinary dividends. Although estimates suggest that about 800 million people are still undernourished, it is thought that this number will drop to about 600 million, largely in sub-Saharan Africa, by 2025 (refs 1, 2). But this is no time for congratulation: although it is hoped the human population will level off at about nine billion by 2050, the population is currently still expanding. Additionally, as populations get richer, meat consumption increases and, because cattle are fed largely on cereals, cereal yields will have to at least double to keep pace.

Achieving this target will face an additional constraint not seen before — lack of available farmland. From 1800 onwards, more food was simply produced by ploughing up virgin land and forest. The land area used for farming



increased about fivefold up to the middle of the twentieth century in step with population increases. The Green Revolution put a brake on this expansion, increasing yields threefold with no need for further expansion[5]. Since 1950, the proportion of the land devoted to farming has barely increased, even though the world population doubled over the same period. We currently use at least half the available good quality soil for agriculture, with the remainder under tropical forests[6]. This leads to an obvious dilemma. Unless we can pull off a second Green Revolution, increasing yield but limiting it to land currently used for farming, there will be further deterioration of natural habitats and biodiversity at a rate that could even threaten the further existence of humanity.

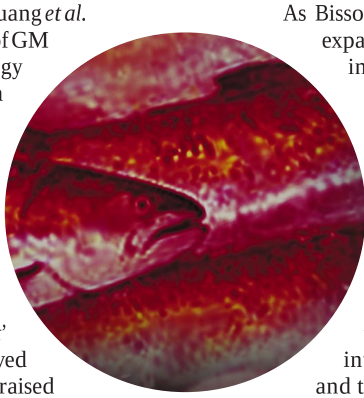
The lessons of history are clear. Successive lurches in population number have driven the development of new agricultural technologies designed to provide food for growing populations. This process of discovery will continue until there is an abundance of food equally enjoyed by the whole world population. We are far from achieving that at the present time, and there is therefore a constant need to examine the state of current agriculture to see where progress needs to be made. The following collection of articles on 'Food and the future' provides a snapshot of the current state of play.

Maximal yields with minimal damage

The state of agriculture across the world varies from the machine-dependent industrial farming of North American prairies to the slash-and-burn method still prevalent in parts of South America and Africa. Uniform solutions are not therefore likely, except that yield on present farmland must be increased, by whatever means. But as in previous malthusian scenarios, new technologies are emerging. Tilman *et al.* (pages 671–677) point to both the merits and demerits of modern industrial agriculture. Cereal yields continue to grow, but the environmental cost of maintaining the high standards of living to which people in the developed world have become accustomed is a cause for concern.

There have been a number of ingenious suggestions for changes in agricultural practice that would improve the environment, while at the same time increasing the efficiency of fertilizer and pesticide use, and maximizing crop yield. One example is 'precision agriculture' in which the state of the soil is monitored metre by metre, with sowing and treatment rates adjusted accordingly. Another is the 'no-till' strategy in which soil structure and biodiversity is conserved by obviating the need for ploughing. Tilman *et al.* make the additional and unusual suggestion that farmers are rewarded for environmental friendliness. An alternative is to point out to economically minded farmers that excessive use of fertilizer and pesticides, as well as being environmentally damaging, also represents a financial loss. Poor management is ultimately responsible for many agricultural problems.

One new and controversial technology is the genetic manipulation of crops, which has the potential to unlock substantial increases in yield. The use of genetically modified (GM) crops has already boosted food and fibre production, raised farm incomes and reduced pesticide usage in the countries that grow them. Huang *et al.* (pages 678–684) describe the Chinese experience of GM crops in the context of the benefits of the technology to the poorest farmers, who have the most to gain provided that GM seed is provided free or at controlled prices, much as in the Green Revolution. Thus the Chinese government has largely kept GM technology to itself, with Chinese universities and institutes developing many new GM crops.



The benefit of GM technology to the poorest farmers is palpable. To a cotton farmer working on a farm of about a hectare in area, the use of '*Bt*' cotton (containing a gene for an insecticide derived from the bacterium *Bacillus thuringiensis*) has raised income by a quarter, cut costs by a third, and slashed pesticide use by three quarters. There are concerns that the cotton bollworm — the pest whose activity *Bt* cotton is designed to curb — might evolve resistance to the insecticide, but ongoing technological development of other GM lines will almost certainly ameliorate the problem if it emerges.

Antagonism in Europe to GM technology, partly because of concerns about the potential for uncontrolled spread of transgenes into weedy or invasive plants, is likely to subside once the real benefits for the consumer emerge. There is much promise in the concept of designer foods in which 'problem' substances such as gluten or common allergenic proteins are eliminated, and useful secondary products (such as the so-called 'neutra-ceuticals') are boosted.

Assessing the impact of land-use change

People who have a high standard of living are reluctant to lose it. But fear of change will have to be mastered, if only because the world refuses to stand still, and constant social adjustments are necessary to accommodate new or long-standing problems. Hails (pages 685–688) discusses the present attitudes to risk and risk assessment concerning crops and food and sets the scene primarily in a European context where dense human populations leave little extra land for biodiversity and leisure. Thus in the United Kingdom, farmland is a major repository of the present, limited biodiversity and its survival is highly dependent on the precise forms of land management used. The farmer is now called upon to fulfil the conflicting roles of steward of the countryside and provider of food, while his or her activities come under increasing scrutiny.

Agriculture has repeatedly met malthusian watersheds — and has overcome them. The current malthusian crisis affecting world fisheries has been caused by the application of modern harvesting to an industry that has yet to escape the ethos of the hunter–gatherer. Pauly *et al.* (pages 689–695) describe the stark situation. Mining the sea at the present rate will result in the extinction of fish species and the destruction of whole ecosystems, with unforeseen consequences. Without massive reductions of fishing fleets, these very real environmental disasters could spread onto the land. Because fish is regarded as a healthy source of protein, fish farming will have to expand substantially, but current research resources to generate the methods to farm marine fish are limited and need considerable investment. A problem is that fish-farming as currently practised is not sustainable, consuming more fish protein than it produces and leaving environmental disaster in its wake.

The fishing industry may be reluctant to change, but this is not true for all food production. The production of wine is a case in point. As Bisson *et al.* show (pages 696–699), winemaking has expanded from a cottage-garden pursuit to a global industry in a matter of a few decades, while remaining responsive to the changing tastes of consumers. Although often thought as an indulgence of the rich, winemaking is increasingly important in the economies of many countries outside the developed world. Oenology is humankind's earliest biotechnology, and stands out as a good example of how the food industry can face the future.

How then did humans end up using agriculture? Diamond (pages 700–707) describes the intriguing history of crop and animal domestication and the forces that changed bands of hunter–gatherers into settled agricultural communities. One important factor is the high birth rate that a settled lifestyle allows, leading to city life and the diversification of activities, while driving hunter–gatherers to the margins. But why did agriculture begin when it did — simultaneously in several different parts of the world, around 10,000 years ago? Climatic change at the end of the last Ice Age may have been the synchronizing factor, although many questions remain about this crucial episode in human history. However domestication began, the long-term benefits eventually outweighed the early disadvantages, such as the emergence of diseases that capitalized on crowded, settled populations. Only now can we really see how the creative achievements in the arts, literature, sciences and architecture could never have happened had the hunter–gatherer model predominated.

Back to the future

From the perspective of ten thousand years, however, some look back to the hunter–gatherer lifestyle with wistful nostalgia. They argue for a retreat from modern technology, so that humankind can achieve some kind of balance with nature. The deleterious environmental consequences of some kinds of food production are very real. This is clearly evident in fisheries, and incorrectly perceived as such by some in the adoption of GM technology. But nostalgia isn't what it used to be: organic farming, sometimes touted as a panacea, is no more sustainable than the fish-farming that produces high-value smoked salmon to those consumers who can afford it. In the world at large, technological change is — as it always has been — driven by the need to squeeze ever greater yields from the same plot of land. In all such arguments, knowledge is the ultimate decider, balanced as usual by economic considerations. Whatever the outcome, the decisions we make now could have repercussions for millennia. □

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