The Economist

The 9 billion-people question

A special report on feeding the world | February 26th 2011

The 9 billion-people question

Also in this section

Acknowledgments
The author is grateful to the many people from the organisations listed below who gave generously of their time and expertise in the preparation of this report. A full list of their names is available online.
Agmark Kenya, the Alliance for a Green Revolution in Africa, the Bill and Melinda Gates Foundation, Biodiversity International, the Biotechnology and Biological Sciences Research Council, Brasil-Agro, the Brazilian Enterprise for Agricultural Research, the Chicago Council on Global Affairs, the Donald Danforth Plant Science Centre, Farm Inputs Promotions—Africa, the Federation of the Industries of the State of São Paulo, the Food and Agriculture Organisation, Global Harvest Initiative, HarvestPlus, the International Finance Corporation, the International Fund for Agricultural Development, the International Livestock Research Institute, the International Maize and Wheat Improvement Centre, the John Innes Centre, Kraft Foods, Moi University, Eldoret, Monsanto, the Abdul Latif Jameel Poverty Action Lab, Nestlé, Rothamsted Research, Syngenta, Western Seed Company, Kenya, the World Bank, World Resources Institute, the United States Department of Agriculture.

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The world's population will grow from almost 7 billion now to over 9 billion in 2050. John Parker asks if there will be enough food to go round

THE 1.6-hectare (4-acre) Broadbalk field lies in the centre of Rothamsted farm, about 40km (25 miles) north of London. In 1847 the farm's founder, Sir John Lawes, described its soil as a heavy loam resting on chalk and capable of producing good wheat when well manured. The 2010 harvest did not seem to vindicate his judgment. In the centre of the field the wheat is abundant, yielding 10 tonnes a hectare, one of the highest rates in the world for a commercial crop. But at the western end, near the manor house, it produces only 4 or 5 tonnes a hectare; other, spindlier, plants yield just 1 or 2 tonnes.

Broadbalk is no ordinary field. The first experimental crop of winter wheat was sown there in the autumn of 1843, and for the past 166 years the field, part of the Rothamsted Research station, has been the site of the longest-running continuous agricultural experiment in the world. Now different parts of the field are sown using different practices, making Broadbalk a microcosm of the state of world farming.

The wheat yielding a tonne a hectare is like an African field, and for the same reason: this crop has had no fertiliser, pesticide or anything else applied to it. African farmers are sometimes thought to be somehow responsible for their low yields, but the blame lies with the technology at their disposal. Given the same technology, European and American farmers get the same results.

The wheat bearing 4 or 5 tonnes a hectare is, roughly, like that of the Green Revolution, the transformation of agriculture that swept the world in the 1970s. It has been treated with herbicides and some fertilisers, but not up to the standard of the most recent agronomic practices, nor is it the highest-yielding semi-dwarf wheat variety. This is the crop of the Indian subcontinent and of Argentina.

The extraordinary results in the centre of the field are achieved by using the best plants, fertilisers, fungicides and husbandry. The yield is higher than the national average in Britain, and is as good as it gets.

Seeds of doubt

But the Broadbalk field shows something else. Chart 1 on the next page tracks its yields from the start, showing how the three different kinds of wheat farming—African, Green Revolution and modern—have diverged, sometimes quite suddenly: in the 1960s with the introduction of new herbicides for Green Revolution wheat, and in the 1980s with new fungicides and semi-dwarf varieties. Worryingly, though, in the past 15 years the yields of the most productive varieties of wheat in Broadbalk

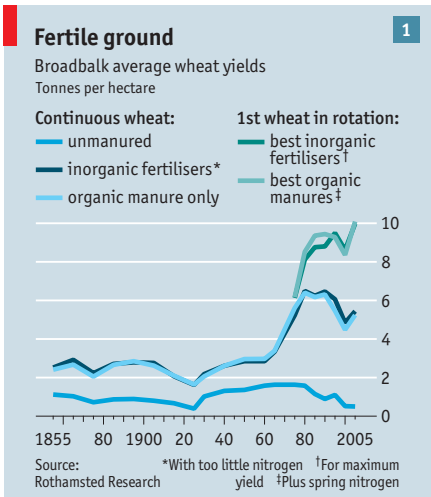
have begun to level out or even fall. The fear is that Broadbalk may prove a microcosm in this respect, too.

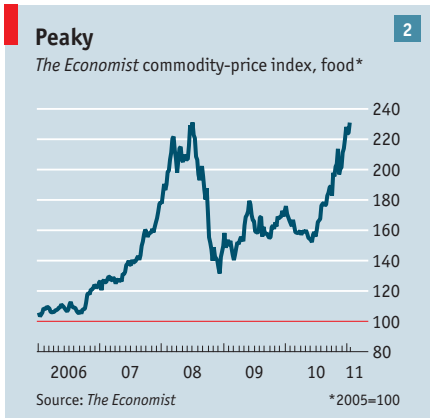
At the start of 2011 the food industry is in crisis. World food prices have risen above the peak they reached in early 2008 (see chart 2). That was a time when hundreds of millions of people fell into poverty, food riots were shaking governments in dozens of developing countries, exporters were banning grain sales abroad and "land grabs" carried out by rich grain-importing nations in poor agricultural ones were raising awkward questions about how best to help the poor.

This time, too, there have been export bans, food riots, panic buying and emergency price controls, just as in 2007-08. Fears that drought might ruin the current wheat crop in China, the world's largest, are sending shock waves through world markets. Discontent over rising bread prices has played a part in the popular uprisings throughout the Middle East. There are differences between the periods, but the fact that agriculture has experienced two big price spikes in under four years suggests that something serious is rattling the world's food chain.

The food industry has been attracting extra attention of other kinds. For years some of the most popular television programmes in English-speaking countries have been cooking shows. That may point to a healthy interest in food, but then again it may not. The historian Livy thought the Roman empire started to decay when cooks acquired celebrity status.

At a meeting of the Group of Eight (G8) industrial countries in 2009 the assembled leaders put food alongside the global financial crisis on their list of top priorities,





promising to find $20 billion for agriculture over three years. This year the current president of the Group of 20 (G20), France's Nicolas Sarkozy, wants to make food the top priority. The Gates Foundation, the world's richest charity, which had previously focused on health and development generally, started to concentrate more on feeding the world. At last month's World Economic Forum, a gathering of businesspeople and policymakers in Davos, 17 global companies launched what they described as "a new vision for agriculture", promising to do more to promote markets for smallholders—a sign of rising alarm in the private sector.

Anything for dinner?

Some of this public and political attention has been sporadic, but it is justified. An era of cheap food has come to an end. A combination of factors—rising demand in India and China, a dietary shift away from cereals towards meat and vegetables, the increasing use of maize as a fuel, and developments outside agriculture, such as the fall in the dollar—have brought to a close a period starting in the early 1970s in which the real price of staple crops (rice, wheat and maize) fell year after year.

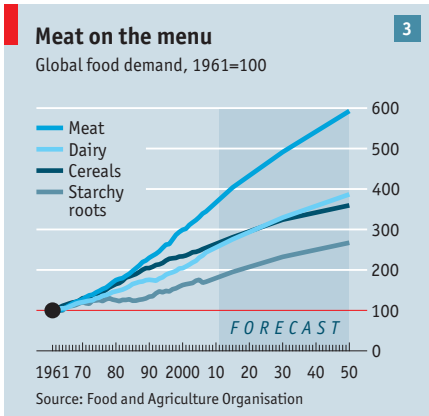
This has come as a shock. By the 1990s most agricultural problems seemed to have been solved. Yields were rising, pests appeared under control and fertilisers were replenishing tired soil. The exciting areas of research in life sciences were no longer plants but things like HIV/AIDS.

The end of the era of cheap food has coincided with growing concern about the prospects of feeding the world. Around the turn of 2011-12 the global population is forecast to rise to 7 billion, stirring Malthusian fears. The price rises have once again plunged into poverty millions of people who spend more than half their income on food. The numbers of those below the poverty level of $1.25 a day, which had been falling consistently in the 1990s, rose sharply in 2007-08. That seems to suggest that the world cannot even feed its current population, let alone the 9 billion expected by 2050. Adding further to the concerns is climate change, of which agriculture is both cause and victim. So how will the world cope in the next four decades?

That question forms the backbone of this special report. The answer to it cannot be a straightforward technical or biological one because food is basic to life. In the Maya creation myth, the first humans were made of maize dough. In the slang of Marathi, a language of west central India, the man on the street is known as "fried bread"—after the workers' favourite snack.

Because food is so important, agriculture—more than any other form of economic activity—is expected to achieve a series of competing and overlapping goals that change over time and from place to place. The world looks to farmers to do more than just produce food. Agriculture is also central to reducing hunger (which is not quite the same thing) and provides many people's main route out of poverty. Food is probably the biggest single influence on people's health, though in radically different ways in poor countries and in rich ones, where the big problem now is obesity. Food is also one of the few pleasures available to the poorest. In the *favelas* (slums) of São Paulo, the largest city in South America, takeaway pizza parlours are proliferating because many families, who often do not have proper kitchens, now order a pizza at home to celebrate special occasions.

Given these conflicting aims, it is not surprising that the food crisis has produced contradictory accounts of the main problem and radically different proposals



for solving it. One group is concerned mainly about feeding the world's growing population. It argues that high and volatile prices will make the job harder and that more needs to be done to boost supplies through the spread of modern farming, plant research and food processing in poor countries. For those in this group—food companies, plant breeders and international development agencies—the Green Revolution was a stunning success and needs to be followed by a second one now.

The alternative view is sceptical of, or even downright hostile to, the modern food business. This group, influential among non-governmental organisations and some consumers, concentrates more on the food problems of richer countries, such as concerns about animal welfare and obesity. It argues that modern agriculture produces food that is tasteless, nutritionally inadequate and environmentally disastrous. It thinks the Green Revolution has been a failure, or at least that it has done more environmental damage and brought fewer benefits than anyone expected. An influential book espousing this view, Michael Pollan's "The Omnivore's Dilemma", starts by asking: "What should we have for dinner?" By contrast, those worried about food supplies wonder: "Will there be anything for dinner?"

This special report concentrates on the problems of feeding the 9 billion. It therefore gives greater weight to the first group. It argues that many of their claims are justified: feeding the world in 2050 will be hard, and business as usual will not do it. The report looks at ways to boost yields of the main crops, considers the constraints of land and water and the use of fertiliser and pesticide, assesses biofuel policies, explains why technology matters so much and examines the impact of recent price rises. It points out that although the concerns of the critics of modern agriculture may be understandable, the reaction against intensive farming is a luxury of the rich. Traditional and organic farming could feed Europeans and Americans well. It cannot feed the world. ■

How much is enough?

The answer is less straightforward than it seems

IN HIS 1981 essay, "Poverty and Famines", Amartya Sen, an Indian economist, argued that the 1943 Bengal famine, in which 3m people died, was not caused by any exceptional fall in the harvest and pointed out that food was still being exported from the state while millions perished. He concluded that the main reason for famines is not a shortage of basic food. Other factors—wages, distribution, even democracy—matter more.

In 1996 the United Nations' Food and Agriculture Organisation (FAO) estimated that the world was producing enough food to provide every man, woman and child with 2,700 calories a day, several hundred more than most adults are thought to need (around 2,100 a day). The *Lancet*, a medical journal, reckons people need no more than 90 grammes of meat a day. On average they eat more than that now. As Abhijit Banerjee of the Massachusetts Institute of Technology says, "we live in a world that is capable of feeding every person that lives on the planet."

Hooked on meat

Indeed, the world produces more than just enough to go round. Allowing for all the food that could be eaten but is turned into biofuels, and the staggering amounts wasted on the way, farmers are already producing much more than is required—more than twice the minimum nutritional needs by some measures. If there is a food problem, it does not look like a technical or biological one.

So why worry about producing more food? Part of the answer is prices. If output falls below demand, prices will tend to rise, even if "excess" calories are being produced. That happened in 2007-08, and is happening again now. Over the past four years prices have been more volatile than they have been for decades. This is bad for farmers (who are left not knowing how and where to invest) and worse for consumers, especially the poor, who risk suddenly being unable to afford basic food.

Another part of the answer is that it is hard to improve distribution and reduce poverty. The world may indeed be growing masses of calories. But the food is not where it needs to be, and biofuel policy is hard to shift (see box, next page). Pushing up supplies may be easier than solving the distribution problems.

But it will still be a daunting task. On one reckoning, in order to keep up with population growth farmers will have to

grow more wheat and maize over the next 40 years than was grown in the previous 500. The balance between what is consumed and what farmers produce matters a great deal.

So how do you keep that balance? Start with consumption, the side of the equation that can be forecast with some accuracy. The forecast rise in world's population, from just under 7 billion at the start of 2011 to just over 9 billion in 2050, is the equivalent of two extra Indias. If you include the 1 billion people who are now going hungry, the additional mouths to feed over the next 40 years add up to three extra Indias.

It is not an impossible task. The increase in world population by 2050 will be around 30%, less than in the 40 years to 2010, when it rose by over 80%. Consumption of wheat, rice and maize roughly tracks population growth but at a higher level, so demand for them will add about a billion tonnes to the 2 billion produced in 2005-07. That is much less than during the previous 40 years, when cereal production rose by 250%.

True, the headline numbers somewhat underestimate the problem. Families have been getting smaller for decades, so there are proportionately fewer children in developing countries than there used to be. Many of those countries are benefiting from a "demographic dividend": an unusually large proportion of young adults in the population, who work hard but eat more than children or older people.

Rise of the carnivores

Moreover, an increasing proportion of the population is living in cities, and dollar for dollar city-dwellers eat more food and especially more processed foods than their country cousins. They also tend to be richer and able to afford pricier food, such as meat. So meat demand will rise strongly. In 2000, 56% of all the calories consumed in developing countries were provided by cereals and 20% by meat, dairy and vegetable oils. By 2050, the FAO thinks, the contribution of cereals will have dropped to 46% and that of meat, dairy and fats will have risen to 29%. To match that soaring demand, meat production will need to increase to 470m tonnes by 2050, almost double its current level. Output of soyabeans (most of which are fed to animals) will more than double, to 515m tonnes.

Overall, the FAO reckons, total demand for food will rise about 70% in the 44 years from 2006 to 2050, more than twice as much as demand for cereals. But that is still less than half as much as the rise in food production in the 44 years from 1962 to 2006. So according to the FAO's Kostas Stamoulis, producing enough food to feed the world in the next four decades should be

Plagued by politics

Biofuels are an example of what not to do

"THIS is the craziest thing we're doing," says Peter Brabeck, the chairman of Nestlé. He is talking about government biofuels targets which require a certain proportion of national energy needs to be met from renewable fuels, most of them biofuels (ie, ethyl alcohol made from crops, usually maize or sugar).

The targets are ambitious. Brazil, Japan, Indonesia and the European Union all say biofuels must supply 10% of energy demand for transport by 2020. China's target for that date is 5%. America aspires to meet 30% of such needs from biofuels by 2030.

Because the energy market is worth vastly more than the market for food, even relatively small targets translate into huge demand for crops. Ethanol currently accounts for just 8% of America's fuel for vehicles, but it consumes almost 40% of America's enormous maize crop. World ethanol production increased fivefold between 2000 and 2010 but would have to rise a lot further to meet all the targets. The FAO reckons that, if this were to happen (which seems unlikely), it would divert a tenth of the world's cereal output from food to fuels. Alternatively, if food-crop production were to remain stable, a huge amount of extra land would be needed for the fuels, or food prices would rise by anything from 15-40%, which would have dreadful consequences.

Not all ethanols are the same. Brazil, the world's second-largest producer, makes its fuel mainly from sugar. Processing plants can go back and forth between ethanol and crystallised sugar at the flick of a switch, depending on prices. Brazil gets eight units of energy for every unit that goes into making it, so the process is relatively efficient and environmentally friendly. In contrast, American ethanol produces only 1.5 units of energy output per unit of input, but its inefficiency is underwritten by government subsidies and high tariff walls. American farmers say that government demand for ethanol is starting to abate, so the impact on maize supplies and prices is more modest now.

All the same, one of the simplest steps to help ensure that the world has enough to eat in 2050 would be to scrap every biofuel target. If all the American maize that goes into ethanol were instead used as food, global edible maize supplies would increase by 14%.

But that is not going to happen. Biofuels have not only diverted crops to fuel but have also diverted public subsidies to farmers without provoking too many objections. Governments are unlikely to abandon biofuels merely because they are inefficient and damaging. "We can't produce biofuels and feed the world's increased population," says Mr Brabeck. But for the moment we will have to.

The wrong shade of green

easier than in the previous four.

Should be, but probably won't be. Increasing food supplies by 70% in the next 40 years may prove harder than it was to raise them by 150% in the previous 40. The main reason: problems with yields.

Yield—tonnes per hectare, bushels per acre or whatever—is the traditional gauge of agriculture's performance. And the growth in yields has been slowing down, from about 3% a year for staple crops in the 1960s to around 1% now.

Yield curb

The earlier period was that of the Green Revolution, an exceptional time. Thomas Lumpkin, the head of CIMMYT, the UN's international wheat and maize research organisation, thinks that farmers in developing countries could often double their harvest by switching to Green Revolution seeds (many of which were developed at CIMMYT by the organisation's most eminent plant breeder, Norman Borlaug). Now, Mr Lumpkin reckons, the best current technologies could perhaps increase yields by 50%—still a lot, but not as spectacular as the earlier improvements. The low-hanging fruit has been plucked and eaten.

The Green Revolution threw resources at plant-breeding, which worked brilliantly. The new seeds enabled grains to absorb more fertiliser and water. But now there is not a lot more water to spare, and fertiliser usage in some places has already passed saturation point (see the next section), so a new Green Revolution will have to make even more efficient use of existing resources. The next 40 years will also have to deal with the potentially profound damage to farming from climate change, which in some parts of the world could reduce yields by one-third.

And disturbingly, for the first time since the Green Revolution, crop yields are growing more slowly than population (see chart 4). To be more exact: growth in population and demand for food have both slowed down, but crop yields have slowed more. Between 1961 and 1990 wheat yields were rising at nearly 3% a year. During that period the world's population was growing by an average of 1.8% a year. Between 1990 and 2007 population growth slowed down to 1.4%, but the rise in annual wheat yields slackened to 0.5%. The growth in rice yields between the two periods halved. Yields of mankind's two most important crops are now almost flat.

A fancier kind of maize

Some argue that these figures are not as worrying as they seem. After all, population growth is slowing and yields of some crops, notably maize, are still rising at a steady pace. And the growth in yields may have slowed not because agricultural technology has hit a wall but because farmers are cutting inputs for environmental reasons, or because they are focusing on quality more than quantity. Indeed, in America farm output is rising but the use of fertilisers and other inputs has been cut back. Breeders have lately been working on wheat for extra protein, not just yield.

If this is the correct explanation, farmers' overall productivity is still increasing, since they are using fewer inputs to get the same output. And that is what some researchers find. Keith Fuglie of the United States Department of Agriculture reckons that total factor productivity in world agriculture—a measure which includes capital, labour and other inputs—is still rising at a healthy 1.4% a year. This reflects a more efficient use of resources. And if farmers are choosing to reduce yields now, they could also push them back up again later.

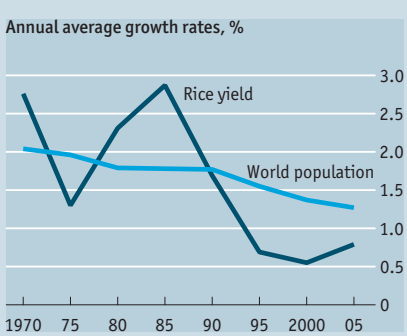
Other researchers, however, think global productivity is indeed slowing down, especially outside China. According to a study using different definitions from Mr Fuglie's, growth in land productivity fell by over one-third between 1961-90 and 1990-2005, and growth in labour productivity fell by two-thirds. And as Mr Fuglie says, even if productivity is rising, it needs to rise more, from an annual gain of 1.4% to 1.75%, he thinks—a big leap. And though farmers might choose to increase yields later, their choice would depend partly on food prices rising more than prices of inputs such as fertilisers, which they may not (in 2007-08 fertiliser prices rose much more than food prices). So even if productivity is increasing—and that is not clear—on its own it is not enough.

And what if the slower rise in yields reflects something more fundamental, the approach of some sort of biological limit in plants? The worry is not that yields are flattening out in farmers' fields, where agronomic practices or the weather or any number of things may be responsible. It is that there may be a problem in breeders' fields where the potential of plants is tested. This possibility is controversial and many breeders reject it. But the idea should not be dismissed out of hand.

The Green Revolution had little to do with making plants bigger: rather, it produced higher yields by persuading more plants to grow in the same space and by getting them to put less effort into growing stalks and leaves and more into seedpods, the part people eat. The nagging fear is that both trends may be reaching a limit.

The number of maize plants in a hectare has risen from roughly 40,000 to 90,000 in the past half-century. There must come a point where plants can no longer be sardined any closer together,

Struggling to keep up 4



Sources: Alston, Beddow and Pardey; Food and Agriculture Organisation, UN Population Division

stalk crushed against stalk. Similarly, at some point it may no longer be possible to persuade plants to put ever more energy into seeds. In animals biological limits are already clear: turkeys are so bloated that they can no longer walk; chickens grow so quickly that they suffer stress fractures. Racehorse speeds have levelled out.

The evidence on whether plants are reaching similar limits is mixed. On the one hand, maize yields in rich countries are continuing to rise, thanks to huge investments by seed companies. A recent Australian study found cereal yields in India, Britain, and Australia are increasing by about 1% a year. Britain's government forecast in 2009 that wheat yields there would rise from 7.7 tonnes per hectare to 11.4 tonnes in 2025 and 13 tonnes in 2050.

On the other hand, trials at CIMMYT's principal wheat-breeding station at Obregon in Mexico indicate a slowdown in potential yield growth to only 0.4% a year. It is also notable that the latest research into plants is focused not on redistributing growth towards seeds but on making the whole plant bigger.

Yields may still be growing, but more slowly, and even that slower growth can no longer be taken for granted. The question is, how much do they need to grow to keep abreast of the growth in the world's population of about 1.2% a year? ■

No easy fix

Simply using more of everything to produce more food will not work

JOSE TOLEDO PISA looks out over the Cremaq farm in remote north-eastern Brazil. Thirty-tonne trucks have finished spreading lime fertiliser to reduce the acidity of the soil. He is about to start planting soya beans first developed by the Brazilian agricultural-research institution, Embrapa, that are suited to the sweltering climate (soyabeans were originally a temperate plant and did not grow well in the tropics). The computer in the farmhouse is checking the temperature, the water and the level of organic material in the soil. Five years ago much of this farm was scrubland. This spring Mr Pisa will reap around 3 tonnes of soyabeans per hectare.

Land, water, fertiliser: three basic components of farming. At Cremaq, Mr Pisa has harnessed new supplies of them to grow abundant crops. But is that the rule or the exception?

Try making deserts bloom

If crop yields are to match the rise in population, then some of them will have to go up dramatically. The world's population is growing at just over 1% a year, so—allowing something extra to feed animals because of rising demand for meat—staple yields will have to rise by around 1.5% a year. This may not sound much, but it is a great deal more than current growth rates. CIMMYT reckons that, to keep prices stable, the growth in rice yields will have to increase by about half, from just under 1% a year to 1.5%; maize yields will have to rise by the same amount; and wheat yields will have to more than double, to 2.3% a year.

Since the 1960s the traditional way of growing more food—by ploughing more land—has been out of favour. That is partly for environmental reasons—much irreplaceable Amazon jungle has already been lost—and partly because many countries have used up all their available farmland. So though the population has soared, the supply of land has not.

However, the potential is not exhausted yet. The biggest agricultural success story of the past two decades has been Brazil, largely because it was able to increase its usable acreage by making its vast *cerrado* (savannah-like grassland) bloom. By reducing the acidity of the soil (as at Cremaq), Brazil has turned the *cerrado* into one of the world's great soyabean baskets.

A new study by the World Bank says the world has half a billion hectares of land with fewer than 25 people per hectare living on them (this excludes land on which farming would be impossible, such as deserts, rainforests or the Antarctic). The area currently under cultivation is 1.5 billion hectares, so if all that extra land could be used it would represent an increase of one-third. In fact a lot of it either should be left alone for environmental reasons or would be too expensive to farm. But that would still leave plenty that could be useful for farming.

Most of it is concentrated in a few countries in Latin America, including Brazil and Argentina, and in Africa in the so-called "Guinea belt", a vast loop of land that stretches round the continent from west Africa to Mozambique. In 11 countries less than half the usable land is farmed. These countries could presumably boost food output by taking in some new land.

But estimates of land availability are contentious. Some put available virgin land at only 10-12% of the current total, not over 30%. The difference depends on cost and politics, not just the physical characteristics of the soil. The *cerrado* itself was once deemed useless for farming.

Limits to growth

And some of this extra land is offset by soil erosion. Africa has some of the most exhausted soils in the world, with less than 1% of organic matter in them, half the level required for good fertility. For centuries African farmers allowed for this by letting the land lie fallow for eight or nine years after a harvest. But with more people to feed they have to squeeze in more harvests, and the soil is no longer recovering.

The chemistry of the soil—the presence in it of phosphorus, nitrogen and so on—is being degraded. That at least can be corrected by fertilisers. But the biology of the soil is also being damaged by the loss of or-

ganic matter, which can take five to ten years to recover. Worst of all, the physical structure changes if the top soil erodes, making it harder for the land to retain water or fertiliser. Top soil can take hundreds of years to replace.

And the more land is turned over to agriculture, the greater the loss of biodiversity. Three-quarters of all the world's plant genetic material may have gone already, mostly by habitat destruction, says Pasquale Steduto of the FAO, and more is going every day. This is a worry because some of the most desirable characteristics of plants are in the wild gene pool and might be needed again one day.

According to the World Bank, "land grabs" (deals in which capital-rich food importers buy up supposedly spare land in poor countries, farm it and ship the produce back home) have had much more impact than expected. Only three years after the first deals, says the bank, they already run to 65m hectares—an eighth of the bank's own estimate of total available land (and a third of the more modest estimates). So a lot of virgin land is already coming under the plough.

On balance, concludes the FAO's Parviz Koohafkan, land is not a decisive problem for world agriculture. But nor, except in a few countries, will it allow big increases in production.

Drink sparingly

Water, on the other hand, is crucial. At the moment it is probably agriculture's critical limiting factor.

According to Nestlé's Peter Brabeck, roughly 4,200 cubic kilometres of water could be used each year without depleting overall supplies. Consumption is higher, at about 4,500 cubic kilometres a year, of which agriculture takes about 70%. As a result, water tables are plummeting. The one in Punjab has fallen from a couple of metres below the surface to, in parts, hundreds of metres down. The rivers that water some of the world's breadbaskets, such as the Colorado, Murray-Darling and Indus, no longer reach the sea.

By 2030, on most estimates, farmers will need 45% more water. They won't get it. Cities are the second-largest users of water, and those in the emerging world are growing exponentially. They already account for half the world's population, a share that will rise to 70% by 2050. In any dispute between cities and farmers, governments are likely to side with cities. Agriculture's share of the world's water used to be 90%, so it has already fallen a long way.

Scarce and precious

It will surely decline further.

The reason water matters so much is that irrigated farming is so productive. It occupies only one-fifth of the world's farmland but contributes two-fifths of the world's food output. Rice, the world's most important crop in terms of calories, is mostly irrigated, and is especially sensitive to shortage of water, stopping growth at the first sign of getting dry.

Water problems will worsen both because irrigated areas will suffer disproportionately from the effects of climate change and because diets are shifting towards meat, which is "thirsty". Arjen Hoekstra, of the University of Twente, says it takes 1,150-2,000 litres of water to produce 1kg of wheat, but about 16,000 litres of water for 1kg of beef. As more people eat more meat, rising demand by farmers will collide with contracting water supplies.

There are things farmers can do. Roughly a third of the water used in fields with ordinary gravity-fed irrigation is reckoned to be wasted (more accurately, it recharges the aquifers without being taken up by plants, which is not quite the same thing). Switching to drip-feed irrigation means that watering becomes more precise, cutting consumption per unit of output. Jain Irrigation, the largest drip-feed company in India, has shown the technology can work for smallholders, cutting their water usage by about 40%. Drip-feed irrigation also boosts overall yields because the plants are watered at the right time and get the right amounts.

Overall efficiency gains in the use of water could be large. Israel wastes only about a tenth of its water, and if everyone were equally efficient, the world's water problem would be much less pressing. Israel makes widespread use of low-volume irrigation such as drip-feed and micro-sprinklers, which is expensive. The FAO reckons that over the next 40 years irrigation will require cumulative investment of almost $1 trillion. That may be forthcoming eventually, but it won't be soon.

No-till agriculture, an agronomic practice in which farmers do not plough up the land but leave part of the previous year's crop on it, also preserves water. The residue acts like a blanket, lowering the soil temperature by a degree or so in the tropics (and thus helping to combat the effects of global warming). It also prevents water run-off and reduces evaporation by 30-40%, reckons Patrick Wall of CIMMYT. As a bonus, adds Shivaji Pandey of the FAO, no-till and low-till farming sequester about 200kg of carbon per hectare per year. In parts of India, the time saved by not ploughing after harvest also makes it possible to grow an extra crop.

So why hasn't this miracle cure been adopted universally? Because of weeds. They like to grow in the mat as much as crops do. It helps to have plants that are genetically engineered to resist weedkillers, but Europe has banned those. This has meant that no-till was used on only 6% of farmland in developing countries and

hardly at all in Europe in 2008.

Agriculture's third basic input is nitrogen. Historically, lack of nitrogen, not lack of land or water, has been its biggest constraint. The invention of a process to synthesise nitrogen cheaply into ammonium, a fertiliser, paved the way for the huge increase in food production in the 20th century. Vaclav Smil of the University of Manitoba in Winnipeg argues that this process, rather than the transistor or computer, was the century's most important invention, and that 2.5 billion people would not be alive without it.

African farmers use an average of 10kg of fertiliser per hectare. Indians use 180kg. India is richer than Africa, but not hugely so. IFAD's Mr Nwanza thinks Africans could double yields by doubling their fertiliser use.

Don't overdose

But there are limits, as China's example shows. Since 1990 Chinese grain production has been roughly stable but the use of fertiliser—which is heavily subsidised—has risen by about 40%. China could cut fertiliser use by at least a third without ill effects. In fact, it would be a blessing. At the moment excess gunk runs off into rivers, gathers in lakes and produces toxic blooms of algae. Likewise, the "dead zone" of the northern Gulf of Mexico is caused largely by overuse of fertiliser in the American Midwest that is making its way down the Mississippi.

So increased fertiliser use would boost yields in some countries and be counterproductive in others. But globally there is little prospect of a big rise because of the expense. Fertiliser prices spiked even more dramatically than food prices in 2007-08. Phosphorus prices soared and have stayed high, reflecting fears that the stuff may be running out. Making fertiliser is energy-intensive, so unless oil prices fall, increasing food production by slathering ever more fertiliser on the land would be inefficient.

Similar considerations apply to dealing with pests and diseases. At the best of times, farmers face the curse of the Red Queen in "Alice Through the Looking-Glass"("A slow sort of country! Now, here, you see, it takes all the running you can do, to keep in the same place."). Predators wage a constant war on plants, and if farmers do nothing the output of a new seed will decline by a percentage point or so every year. This is why new seeds are needed all the time.

There are signs that the burden of disease may be increasing. Rothamsted Research, home to the Broadbalk experiment, has been tracking aphid infestations for 50 years. In 2000 no aphids had a particular resistance mechanism called mace. Now 70-80% do. The aphid that causes potato blight now appears a month earlier than it used to, so it feeds on the plant at a more vulnerable point in its life.

The greater incidence of disease may be caused by many things: more insects surviving winter; the banning of dangerous pesticides; cuts in the budgets of institutions that conducted research into diseases; even globalisation. The corn-borer moth, native to Central and North America, first appeared in Europe in 1999 in Kosovo, presumably on the boots of American peacekeepers. It has since spread in concentric circles each year and is now eating into maize crops in Germany and Italy.

Waste not, want not

Far too much food never reaches the plate

MANCUR OLSON, an American economist, talked about $100 bills lying on the sidewalk to express the idea of easy gains. The amount of food that is wasted represents a gigantic stack of $100 bills. Both in rich countries and poor, a staggering 30-50% of all food produced rots away uneaten. According to Josef Schmidhuber of the FAO, in Africa the post-harvest waste largely explains why many smallholders are net purchasers of food even though they grow enough for their families to eat.

In poor countries most food is wasted on or near the farm. Rats, mice and locusts eat the crops in the field or in storage. Milk and vegetables spoil in transit. These might be considered losses rather than waste. Kanayo Nwanze, the head of the International Fund for Agricultural Development, reckons that such losses could be reduced by half. That would be the equivalent of a rise in output of 15-25%, which would go a long way to providing the extra food needed by 2050.

Unlike in rich countries, much of the waste in poor ones is a matter of money, not behaviour. Grain is often heaped on the ground and covered with a sheet: no wonder the rats get at it. Losses could be reduced by building new silos and better roads and providing more refrigeration, but those things are expensive. The African Development Bank is financing a seven-year programme to reduce waste by 3% a year. Given the scale of the losses, says Divine Njie of the FAO, who worked on the scheme, "we were surprised at how modest the targets were." But 3% a year adds up to a 20% reduction in waste over seven years, a good start.

There is likely to be more of this sort of investment in future. To meet demand in the emerging megacities, more processed food is being sold in supermarkets and less raw food in markets. Nutritionists worry about the resulting loss of quality, but there are big gains in quantity. Food processors and retailers use modern silos, proper trucks and refrigeration—the very things the rural poor lack.

Rich pickings

Rich countries waste about the same amount of food as poor ones, up to half of what is produced, but in quite different ways. Studies in America and Britain find that a quarter of food from shops goes straight into the rubbish bin or is thrown away by shops and restaurants. Top of the list come salads, about half of which are chucked away. A third of all bread, a quarter of fruit and a fifth of vegetables—all are thrown out uneaten. In America this amounted to 43m tonnes of food in 1997; in Britain to 4m tonnes in 2006.

If all rich countries waste food at the same rate as Britain and America, very roughly 100kg per person per year, the total waste adds up to 100m tonnes of food a year, equivalent to one-third of the entire world's supply of meat—an astonishing quantity. If Western waste could be halved and the food distributed to those who need it, the problem of feeding 9 billion people would vanish.

But it can't. Western spoilage is a result of personal habit and law. Education or exhortation might make a difference, but the extent of waste is partly a reflection of prices: food is cheap enough for consumers not to worry about chucking it out, and prices seem unlikely to rise by enough to change that attitude.

These problems are onerous, but most are probably tractable. Climate change is not. Global warming upsets the world's water cycle, increases the burden of pests, desiccates soil and reduces yields. In 2010 the world got an unpleasant taste of what climate change might bring. During the summer the jet stream (air currents at 7,000-12,000m above sea level which affect the winds and weather) changed its course. That seems to have been linked to the catastrophic floods in Pakistan and huge forest fires in Russia which help explain the big food-price rises in the second half of last year.

Agriculture is itself a big contributor to climate change. According to the Intergovernmental Panel on Climate Change, farming directly accounts for 13.5% of greenhouse-gas emissions, and land-use changes (often cutting down jungle for fields) are responsible for a further 17.4%. That adds up to almost one-third.

Agriculture is responsible for between half and two-thirds of emissions of two especially toxic greenhouse gases, methane and nitrous oxide. These stay in the atmosphere for years, absorb a lot of radiation and, weight for weight, have many times the impact of carbon dioxide. So even if nothing else were happening, farmers would be under pressure to cut emissions.

But a lot else is happening. An increase of 2°C in global temperatures, says Hans-Joachim Braun, the head of CIMMYT's wheat programme, could cause a 20% fall in wheat yields. This would exceed any possible gains from warming in areas currently too cold to grow crops and would also offset the benefits of rising carbon-dioxide concentrations. Plants eat CO_2, so if there is more of it in the atmosphere, photosynthesis should increase and yields rise. But no one knows by how much.

The day of the locust

Climate change also affects the rhythm of the seasons. Winters arrive later or spring earlier. Rainy seasons become shorter, milder or more intense. All living things depend on the heartbeat of seasonal change. In spring, caterpillars time their emergence to coincide with the bud burst of trees; birds start nesting when they can feed those newly emerged caterpillars to their fledglings. Any disruption to the seasonal rhythm tugs at the web of life. For example, in parts of Mozambique where villagers cultivate maize on the flood plain of the Zambezi river, the rainy season now begins later, so the crop is sown later, shortening its growing period.

Out of synch

In 2009 Oxfam, a British charity, asked thousands of farmers in a dozen countries what worried them most about climate change. Their biggest concern was not higher temperatures but disruptions to the natural cycle. "I know I am supposed to sow by a certain time or date," said Mohammed Iliasuddin, a farmer in Bangladesh. "That is what my forefathers have been doing. But then for several years the temperature and weather just does not seem right for what we have been doing traditionally. I do not know how to cope with the problems."

When the International Food Policy Research Institute (IFPRI) tried to work out the impacts of climate change on the main cereal crops, almost all its results suggested that yields in 2050 are likely to be lower than they were in 2000, sometimes much lower. Almost half the forecasts showed yield reductions of 9-18% by 2050. One came up with a drop in rainfed-maize yields of 30%. The most vulnerable crop turned out to be wheat, with the largest losses forecast in developing countries. The Indo-Gangetic plain, home to a seventh of mankind and purveyor of a fifth of the world's wheat, is likely to be especially hard hit. ■

Doing more with less

The only reliable way to produce more food is to use better technology

IT IS 7am at Kabiyet Dairies in the emerald hills of western Kenya. The dairy is five miles down an almost impassable track, and you would think milk would turn to butter long before it arrives. Yet the place is heaving with farmers waiting for their produce to be tested, carrying it in pails on trucks, on the backs of motorbikes or on their heads. The dairy opened only 18 months ago and may seem basic, yet it has just struck a deal to sell milk to an international processing plant in Nairobi. Farmers get 26 shillings a litre, more than twice what they were paid before the dairy opened its doors.

Laban Talam, a 30-year-old villager, has a smile on his face. He farms just under a hectare on a hillside overlooking the dairy. Two years ago he was scratching a living, supplementing his earnings from one cow, a native longhorn, with odd jobs outside farming. Now he has five cows, three of them Holsteins who give twice as much milk as the native breed. He rents extra land from his neighbour, has rebuilt his house, grows pineapples for export and has installed a biomass pump. His children go to a private school.

Kabiyet Dairies is only one agricultural success story among many. Brazil, by investing heavily in research, has turned itself into the first tropical farm giant, joining the ranks of the temperate-food superpowers such as America, Europe and Canada. It did so in a single generation, thanks mainly to big commercial farms. Vietnam, through policy changes (especially freeing up small-scale private agriculture), turned itself from one of the world's largest importers of rice into the world's second-largest exporter.

So it is possible to grow more food, ▸▸

Time for an efficiency drive

more efficiently, on both a regional and a national scale. But can it be done on a global scale, which is what is needed to feed 9 billion people? If so, how?

Because of the constraints described in the previous section, there will not be big gains in food production from taking in new land, using more irrigation or putting more fertiliser on existing fields. Cutting waste could make a difference (see box in previous section), but there are limits. The main gains will have to come in three ways: from narrowing the gap between the worst and best producers; from spreading the so-called "livestock revolution"; and—above all—from taking advantage of new plant technologies.

The huge gap between the best and worst producers in roughly comparable farming areas shows the scope for improvements. Both eastern and western Europe are good for growing wheat. Yet west European farmers achieve yields of up to 9 tonnes per hectare, whereas east European ones get just 2-4 tonnes. The discrepancy is much wider than differences in incomes or soil quality might suggest.

Or take the example of maize seed. According to Pioneer, a big seed company, central Ghana has some of the best maize land in the world, yet only 3% of the country's seed is the hybrid kind that can take full advantage of it. In contrast, Brazilian land is less good, but 90% of its seeds are hybrid ones. The country is now the world's third-largest exporter. If Ghana bought more hybrid seeds, it could presumably achieve something closer to Brazilian yields.

Why don't the laggards catch up? A good place to look for an answer is Africa, the part of the world that has most conspicuously failed to feed itself over the past 50 years. Five years ago, says Joe deVries, head of crop research at the Alliance for a Green Revolution in Africa (AGRA), the big problems in Africa were prices and investment. Farmers were getting too little for their produce and no one was doing any research into "African crops" such as sorghum and cassava. Now prices are higher—a benefit to producers, at least—and the "African crop" problem is being solved. New semi-dwarf sorghum has three times the previous yield, and genetic research has shown how to control cassava's great scourge, viral disease.

The problem now is to get those improved seeds to the farmers. Around Kabiyet, Western Seed Company, a small outfit that develops its own varieties of maize for smallholders, doubled production in 2010 and still sold out two months early. It is one of 45 seed companies set up with AGRA's backing, and Mr deVries reckons they will need 100 to meet prospective demand. At present only 10% of Kenya's farmers are using new seeds, but Mr deVries hopes that by 2015 the figure will have risen to half.

When India began its Green Revolution in the 1960s, it had 388km of paved roads per 1,000 sq km of land, and only about a quarter of its farmland was irrigated. Ethiopia now has just 39km of roads per 1,000 sq km, and less than 4% of its land is irrigated. So the remaining problems in Africa are vast. Moreover, says Don Larson of the World Bank, farming in that continent is intrinsically harder to change than in east Asia because it is more varied. In east Asia, if you invent an improved rice variety, every farmer for hundreds of miles around can use it because the land and climate are much the same. In Africa, soil and climatic conditions are much more diverse and farmers a few hundred yards apart may need different seeds.

But better technology is removing some of the barriers. Since 2008 African food production per person has been rising for the first time in decades. Rwanda and Malawi have begun to export food (admittedly in Malawi's case thanks to massive and unaffordable fertiliser subsidies). For now Africa is still a net food importer, but a recent Harvard study for the presidents of East African countries argued that it could feed itself in a generation. Even if that proves optimistic, Africa could surely increase food production by more than 1.5% a year. "We didn't know how the Green Revolution would come to Africa," says Mr deVries. "Now we do."

The second main source of growth will consist of spreading a tried and tested success: the "livestock revolution". This consists of switching from traditional, open-air methods of animal husbandry, in which chickens and pigs scratch and root around the farm, eating insects, scraps and all sorts of organic waste, to closed "battery" systems, in which animals are confined to cages and have their diet, health and movement rigorously controlled. This entails huge losses in animal welfare, and European consumers are reacting against the system. But there are also gains in productivity and sometimes even in welfare, by reducing losses from diseases and predators that in traditional systems can be distressingly high.

Animal spirits

Improving livestock farming is important because of meat's growing share in the world's diet. Meat consumption in China more than doubled in 1980-2005, to 50kg a year per person. Between now and 2050, meat's share of calories will rise from 7% to 9%, says the FAO; the share of dairy produce and eggs will rise more.

Livestock matters for many reasons. It provides financial security in poor countries, where herds are often a family's savings. It can affect people's health: new infectious diseases are appearing at the rate of three or four a year, and three-quarters of them can be traced to animals, domestic and wild. Avian flu is just one example. Livestock also plays a part in global warming. Much of the methane in the atmosphere—one of the worst greenhouse gases—comes from cattle belching.

Since the 1980s livestock production has far outstripped that of cereals. World meat output more than doubled between 1980 and 2007. Production of eggs rose from 27m tonnes to 68m over the same period. Some countries have done better still. India has the world's largest dairy

herd. Its milk production trebled, to 103m tonnes, over a period when global milk output increased by half. Brazil increased its production of chickens fivefold in 1987-2007 to become the world's largest exporter. Most spectacularly, China raised it output of both eggs and milk tenfold.

For sheer efficiency, there is little question that battery systems do a better job than traditional methods. A free-range hen scratching around might lay one or two eggs a week. Feeding her costs nothing, giving a net gain of 50-100 eggs a year. A battery chicken will lay six eggs a week. She might cost the equivalent of 150 eggs to feed, producing an annual net gain of 150 eggs. And selective breeding has made her more economic to keep. Battery chickens used to need 4kg of feed for 1kg of eggs; now they need only 2kg.

Moreover, it is almost impossible to scale up a farmyard operation: there are only so many insects to eat, and so many hens one family can look after. And to breed the most productive hens which convert their feed most efficiently into eggs and are most resistant to disease, you need large flocks.

So there are two reasons for thinking that the livestock revolution will continue. One is that some countries still lag behind. An example, surprisingly, is Brazil, which has just one head of cattle per hectare—an unusually low number even for a country with so much land. Roberto Giannetti da Fonseca, of the São Paulo industry federation, says Brazil should be able at least to double that number—which could mean either doubling beef production or using half the area to produce the same amount.

Carlos Sere of the International Livestock Research Institute thinks traditional systems could borrow some of the methods of closed battery-farm systems—notably better feeding (giving a small amount

Our daily bread

Bringing wheat up to scratch

FOR the past decade maize has been the seed companies' favoured crop. Research spending on it runs at $1.5 billion a year, four times that for wheat. And it shows. Maize yields in 1990-2008 rose by 1.8% a year, close to their long-term average; wheat yields increased by less than half that, half their historic average.

Wheat needs more research. It is the most nutrient-rich of the world's cereals and the most widely planted crop. It is also the staple most vulnerable to climate change. A few thousand commercial species are carefully grown and preserved. But hundreds of thousands of older varieties and wild relatives are left to the vagaries of land-use change, global warming and chance. This is a worry because some of the most desirable characteristics of plants—taste, drought- and pest-resistance—originally came from the wild gene pool, which will be needed again one day.

Wheat is physiologically different from maize in two main ways, making big genetic improvements harder to achieve. First, its genes are arranged in pairs of three, not single pairs, as with humans. That makes the wheat genome enormous, far larger than that for maize (or people). Second, the reproductive parts of the wheat plant are close together, so wheat tends to self-pollinate. In contrast, the male tassels of maize are a foot or more away from the female cob and are easily blown by the wind to other plants. So maize readily produces hybrids, which tend to be more vigorous. It is possible to produce wheat hybrids, but it takes more trouble and expense.

However, wheat is now the new frontier of plant technology. Graham Moore of the John Innes Centre in Norwich is targeting part of a chromosome called Ph1 which ensures wheat genes pair up correctly. Ph1 gives wheat's genome its stability but has to be switched off to make it easier to slot in new genes. It then has to be switched back on again, otherwise the plant will mutate unpredictably. Mr Moore has found that bathing the genetic material with a substance called okadaic acid (a toxin that occurs in mussels) enables Ph1 to be switched on and off.

Built-in Growmore

At the same time Mr Moore's colleague, Giles Oldroyd, is investigating how some plants, such as legumes (peas and beans), make their own fertiliser, in the hope of transferring this trait to cereals. Bacteria in the nodules of leguminous plants' roots convert soil nitrogen into ammonia, the feedstock of nitrogen fertiliser. The plants shelter the bacteria and use the ammonia they make in ways that are encoded in their genes, so in principle the genes could be transferred to other plants. Since fertilisers represent a third of the input costs of wheat, enabling it to make its own nitrogen would offer dramatic savings, though Mr Oldroyd concedes that this may be a 30- or 40-year project.

Meanwhile, scientists at the Wheat Yield Consortium are trying to produce bigger wheat plants by speeding up the rate of photosynthesis. This is the process plants use to convert carbon dioxide into organic materials, using a catalyst called rubisco. Rubisco is unusual. Its catalytic rate is exceptionally slow and it is not good at distinguishing between CO_2 and oxygen. So instead of using CO_2 to build sugars and getting rid of oxygen, which is what happens in photosynthesis, it sometimes uses oxygen, does not build up the sugars and gets rid of CO_2 (a process called photorespiration). If rubisco could be persuaded not to catalyse photorespiration, plants would grow more vigorously.

There are three ways to do that. One is to use more and better rubisco. A second way is to tinker with the proteins that influence rubisco, such as rubisco activase, which has produced promising results in tobacco plants. Third, it might be possible to manipulate the environment inside the leaves of the plant so rubisco catalyses photosynthesis more reliably. Some plants, such as maize and sugar cane, have special cells in which to capture CO_2. The Gates Foundation is financing research to try to breed those characteristics into rice which, like wheat, lacks this extra cell.

It is a long shot, but by 2050 wheat plants could be making their own fertiliser, as well as having acquired desirable genetic characteristics from other plants and being larger and more productive. Whether that is enough to overcome many people's horror of genetic engineering remains to be seen.

of animal feed makes a big difference to the weight of range-land cattle) and the introduction of new breeds for better yields (as Kabiyet did by switching from longhorn to Holstein cattle).

The second reason for expecting further gains is that recent genetic analysis could improve breeding dramatically. About a third of the livestock revolution has come about through selecting and breeding the best animals. Another third comes from improved feeding and the remainder from better disease control. In the 1940s and 1950s breeding relied on the careful recording of every animal in the herd or flock; in the 1970s on artificial insemination by the best sires; and in the 1980s on embryo transfers from the best females into ordinary breeding animals.

New genetic analysis now promises to bring in another stage, says the FAO's Henning Steinfeld. It allows breeders to select traits more precisely and thus speeds up breeding by reducing generational intervals: if you know which genetic traits an animal has, there is no need to wait several generations to see how things turn out.

This will not happen everywhere. Europeans and—to some extent—Americans are increasingly influenced by welfare concerns. They jib at confining animals. The European Union has banned certain kinds of cages, and California is following suit. But, so far, people in emerging markets, where demand for meat and animal products is growing fast, are less concerned about such things, so the next stage of the livestock revolution will mainly be concentrated there.

GM and after

This will make some difference but the change likely to generate the biggest yield gains in the food business—perhaps 1.5-2% a year—is the development of "marker-assisted breeding"—in other words, genetic marking and selection in plants, which includes genetically modifying them but also involves a range of other techniques. This is the third and most important source of growth.

"Until recently we knew little about how plants function, how they perceive heat and cold, how they flower, and so on," says Caroline Dean of Britain's John Innes Centre. That is changing, thanks to greater understanding of plant genetics as well as to a dramatic fall in the costs of gathering genetic information.

Ms Dean has worked out, for example, how plants "remember" the length of time winter has been going on and do not therefore mistake a mild spell in January for spring. The answer, it seems, is by turning off a gene after a certain period of cold weather. This process is finely adjusted, so in Sweden the plant switches off the gene later than one of the same species in southern England.

Cheap, cheap

At the same time the price tag on gathering genetic data is now much lower than it used to be. Gary Atlin, a maize breeder at CIMMYT, reckons that whereas a couple of years ago the cost of identifying a single gene in a single plant was $2, now it is about 15 cents. That is still too high for many breeding operations, but work now being done jointly by CIMMYT and Cornell University should cut this to $30 per million genes. "This is Moore's law for plants," says Mr Atlin, referring to the rough rule that computing power doubles every two years for the same price. The cost of genetic identification will soon stop being a serious constraint.

The public debate on plant genetics focuses almost entirely on the pros and cons (mostly cons) of genetic modification—putting a gene from one species into another. A gene from a soil bacterium, *Bacillus thuringiensis*, for example, when spliced into maize, makes the plant resistant to herbicides; this enables farmers to plant maize, spray the crop with a weedkiller and end up with a field of nothing but maize. In Europe it is illegal to plant such maize. The biggest advantage of genetic selection, however, is probably not that it makes it possible to grow transgenic crops ("Frankenfoods"), but that it allows faster and more precise breeding.

Imagine the genetic material of plants as a vast library, with billions of books. This library has no catalogue, and none of the books has an index or table of contents. It is still possible to discover what is in the library by reading every volume. That is roughly what plant breeders have done in the past, painstakingly planting hundreds of varieties of a single species and discovering traits by breeding numerous generations from them.

Genetic marking is the equivalent of giving every book a title, table of contents and index—and with much greater speed and accuracy than any librarian could manage. Monsanto has a "corn chipper" which takes a small amount of genetic material and generates a DNA profile of hundreds of maize seeds simultaneously in seconds. It leaves the seed alive, so breeders, having mined the computer data from this and every other seed in Monsanto's vast library, can go back to a seed they like and breed from it. It is possible literally to find one plant in a billion.

Such gains are likely to snowball. In 1997 Monsanto introduced a variety of corn resistant to various pests. It fully controlled four of 15 common "above-ground" corn pests like corn borers, cutworms and stinkbugs, and partially suppressed three more. In 2004 the company introduced a successor that controlled nine of the 15 above-ground pests and seven of the eight that lived in the soil. The 2010 version controlled nine above-ground pests and seven in the soil, and suppressed three more.

At the moment the genetic evolution is just beginning. The genomes of most important crops have been sequenced only fairly recently, and that of wheat is only partly done. There are only a handful of genetically modified crops. Commercial firms have concentrated most of their efforts on only one or two traits controlled by individual genes, such as disease resistance. But the future, argues Giles Oldroyd of the John Innes Centre, lies in traits controlled by multiple genes and genetic "pathways", that is, interactions between groups of genes.

The most important of these is yield. Over the next 40 years yields need to rise by around 1.5% a year to feed mankind adequately. Maize, which has had by far the most genetic research, is the only crop whose yield is growing by more than that. If genetic selection can be extended to wheat, rice and soyabeans, that should go a long way to feeding the world by 2050. ■

Not just calories

People also need the right nutrients

"PROVIDING the quantity of calories is manageable," says Joachim von Braun of the University of Bonn. "The big issue is nutrition." In the past 30 or 40 years diets have improved. There are now proportionately fewer malnourished people in the world than there used to be (though the absolute number is high and rising). Fewer people fail to grow to their proper height and weight because of poor childhood diets. India is a peculiar exception to this rule: for reasons no one understands, Indians of all income levels now eat less food, and of a lower quality, than they used to, and than you would expect.

But although most people get enough calories, they still suffer huge deficiencies, especially in four nutrients: iron, zinc, iodine and vitamin A. Iron deficiency makes over 1.5 billion people anaemic, including half of all women of child-bearing age in poor countries. Lack of vitamin A causes up to half a million children to go blind each year, of whom half die within a year. Zinc deficiency is thought to be responsible for about 400,000 deaths a year.

Such deficiencies have long-term consequences for the whole society. In Tanzania, children whose mothers were given iodine capsules when pregnant stayed at school for four months longer than their siblings born when the mother did not get those capsules. Children suffering from nutrient deficiencies cannot concentrate and have lower scores in tests for cognitive ability. And there seems to be a link between nutrition in childhood and earnings in later life. In Kenya children who were given nutrition-improving deworming pills for two years earned about $3,000 more over their lifetime than those who got them for only one year. Malnourished boys also do worse in the marriage market.

Drowning in a sea of food

On the face of it, the obesity epidemic in rich countries presents exactly the opposite problem. For the first time in history, more calories do not mean better health. The epidemic is spreading to less well-off places: Mexico has the second-largest share of obese people after America; Guatemala's obesity rate has quadrupled in 30 years. The overweight are obviously not troubled by a shortage of food. But a large group of people in rich countries does suffer from nutritional deficiencies: the elderly. They need more calcium and vitamins with advancing age, and many do not get them. Half of those over 75 in hospital are reckoned to be nutrient-deficient, as are many obese people.

Nutrient deficiency is not easy to cure. In poor countries, vitamin supplements—a common expedient—reach less than half of those who most need them, the rural poor. And programmes to hand out vitamin A supplements in massive doses to reduce child mortality have brought little discernible improvement. Michael Latham of Cornell University, reviewing the history of such handouts, speaks of "the great vitamin-A fiasco".

Cultural norms are a constant obstacle. Abhijit Banerjee of the Massachusetts Institute of Technology quotes George Orwell's "Road to Wigan Pier" on the British working class:

> The basis of their diet is white bread and margarine, corned beef, sugared tea, and potatoes—an appalling diet. Would it not be better if they spent more money on wholesome things like oranges and wholemeal bread, or if they … ate their carrots raw? Yes it would, but the point is, no ordinary human being is ever going to do such a thing. The ordinary human being would sooner starve than live on brown bread and raw carrots. And the peculiar evil is this, that the less money you have, the less inclined you feel to spend it on wholesome food. A millionaire may enjoy breakfasting off orange juice and Ryvita biscuits; an unemployed man doesn't.

The fat of the land

Better nutrition, in short, is not a matter of handing out diet sheets and expecting everyone to eat happily ever after. Rather, you have to try a range of things: education; supplements; fortifying processed foods with extra vitamins; breeding crops with extra nutrients in them. But the nutrients have to be in things people want to eat. Kraft, an American food manufacturer, made Biskuat, an "energy biscuit" with lots of extra vitamins and minerals, into a bestseller in Indonesia by charging the equivalent of just 5 cents a packet. It also did well in Latin America with Tang, a sweet powdered drink with added nutrients, marketing it to children for the taste and mothers for its nutritional value.

It is also possible to breed plants that contain more nutrients. An organisation called HarvestPlus recently introduced an orange sweet potato, containing more vitamin A than the native sort, in Uganda and Mozambique. It caught on and now commands a 10% price premium over the ordinary white variety. The local population's vitamin intake has soared.

HarvestPlus has a pipeline of "biofortified" crops: cassava with vitamin A due to be released in Nigeria this year; pearl millet with extra iron and zinc, to be launched in India in 2012; beans with extra iron, also in 2012; rice with zinc, due for release in 2013. But again there are limits: it is hard to breed the full recommended daily dose of nutrients into plants this way.

John Hoddinott of IFPRI says the lesson of previous failures is that you have to select your targets: focus on the main deficiencies and on those for whom you can do most good, especially infants. Feeding the world is not just about calories but nutrients, too; and it is not about scattering them far and wide but pinpointing the groups who can and will eat them. ■

A prospect of plenty

For the first time in history, the whole of mankind may get enough to eat

FOR 10,000 years farmers have produced food for mankind. That has been the basis of life. "When tillage begins," wrote Daniel Webster, "other arts follow. The farmers, therefore, are the founders of human civilisation."

This special report has argued that over the next 40 years farmers will find it harder to produce enough for everyone because of constraints on land, water and fertilisers. There is some room for expansion onto virgin land, but not much. There is less water because of competition from fast-growing cities. Returns on fertiliser use are diminishing. And government policies that boost biofuels and restrict trade will get in the way.

But though not easy, it should be perfectly possible to feed 9 billion people by 2050. A start has been made to boosting yields and reducing harvest losses in countries that lag behind, notably in Africa. The "livestock revolution" can be furthered by genetic improvements. Above all, advances in plant genetics should enable breeders to push up the annual growth in yields of staple crops from 0.5-1.0% to 1.5%—which would produce enough for everyone. By 2050 the growth in the world's population will have slowed almost to zero, changes in food demand will come mainly from changing diets and the biggest food-supply problem will be dealing with the effects of climate change.

It would be a huge relief if those 9 billion could be fed without large disruptions of supplies or price spikes. Food is the world's secret stabiliser—or destabiliser. As George Marshall said in 1947, it "is the very basis of all reconstruction; hunger and insecurity are the worst enemies of peace." But there will be winners and losers. And the strain is likely to set off conflicts along the way: over water and land; over policies; between farmers who want higher prices and consumers who don't; and between countries or groups of countries.

In 2007-08 and again in 2010-11, relatively small changes in food markets triggered sharp rises in prices. That might have been understandable as a response to, say, a surge in demand from China and India. But, as Shenggen Fan of IFPRI points out, these giants do not import much food. Instead, prices spiked in reponse to temporary factors, such as the fall in the dollar, export bans and panic buying.

Higher prices provide farmers with incentives to produce more, making it easier to feed the world. But they also impose costs on consumers, increasing poverty and discontent. If passing fancies like trade bans can almost double world food prices twice in four years, imagine what a stumble in efforts to boost yields might do.

Climate change will add to the strains, and not only by disrupting the weather. If there were a real carbon price, farmers would think of their fields in terms of the carbon embodied in crops and soil. That in turn would influence what they grow (elephant grass, perhaps, rather than wheat). And they would have to decide not just which crops to plant but whether to use them for food, carbon capture or things like bio-industrial raw materials. Competition for crops is already a problem, and likely to get worse.

Given these strains, and the political ramifications of food, efforts to feed the 9 billion will sharpen geopolitical conflicts and speed up shifts that are happening anyway. Some of the most successful food producers over the past 20 years have been the BRIC countries (Brazil, Russia, India and China). Catherine Bertini of the Chicago Council on Global Affairs, a think-tank, points out that the biggest contributors to the World Food Programme, which plays an important part in humanitarian crises, are all BRICS; and that when secretive North Korea began to engage in talks over nuclear disarmament, the first countries it spoke to were big grain exporters.

The BRICS' influence on food markets will rise as Europe's declines. The old continent's decision to turn its back on genetic modification and the livestock revolution may be understandable—but given the need for higher yields, Europe is in danger of marginalising itself. America is likely to retain its place as the world's largest food exporter, but its position is no longer unchallenged.

Worth a detour

There are plenty of reasons to worry about food: uncertain politics, volatile prices, hunger amid plenty. Yet when all is said and done, the world is at the start of a new agricultural revolution that could, for the first time ever, feed all mankind adequately. The genomes of most major crops have been sequenced and the benefits of that are starting to appear. Countries from Brazil to Vietnam have shown that, given the right technology, sensible policies and a bit of luck, they can transform themselves from basket cases to bread baskets. That, surely, is cause for optimism. ■

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