05

Combating Hunger

Cooking pots in a village in the Ivory Coast. © iStockphoto

Hunger is a powerful word that encompasses the complex patterns of undernutrition amongst the world's poor. The hungry include:

- About a billion people who are chronically undernourished (i.e. consuming less than 1,800 calories per day);[1]
- 130 million children under five who are underweight for their age (more than two standard deviations below the median);[2]
- 400 million women who are anaemic;[3]
- Over 200 million children who are vitamin A deficient.[2]

In the developed countries hunger is a feeling of slight discomfort when a meal is late or missed. By contrast, in the developing countries hunger is a chronic problem. Television images convey the realities of hunger – emaciated and starving children – in war-torn countries or in the aftermath of droughts, floods or other calamities. But hunger in the developing countries is a day-to-day occurrence, both persistent and widespread. Children are especially vulnerable, from their time in the womb until the age of five. During this period of rapid physical and cognitive development, even short-term dietary deprivation can have lasting effects. Undernutrition during this time leads to stunted growth, low brain development, low life expectancy, poor educational attainment and inter-generational poverty. Hunger and poverty are inextricably linked, one resulting in the other, so creating a trap from which escape is very difficult.[2,4,5]

It is the persistence of hunger and its consequences that have made hunger a key target of the MDGs. While many of the Asian developing countries are going to reach the MDG of halving the proportion of hungry people by 2015, in Sub-Saharan Africa only Ghana is going to achieve this (see Chapter 4).

1. The chronic crisis

Hunger has grown much worse as a result of the 2008 food price crisis, which has added over a hundred million people to the numbers of chronically undernourished.[6] This is because even the poorest people are dependent on purchased food. They spend a much higher proportion of their income on food than wealthier people, making them particularly vulnerable to price increases.

A five-person household living in Bangladesh on the poverty line of US$1 a day per person typically spends its US$5 as follows:

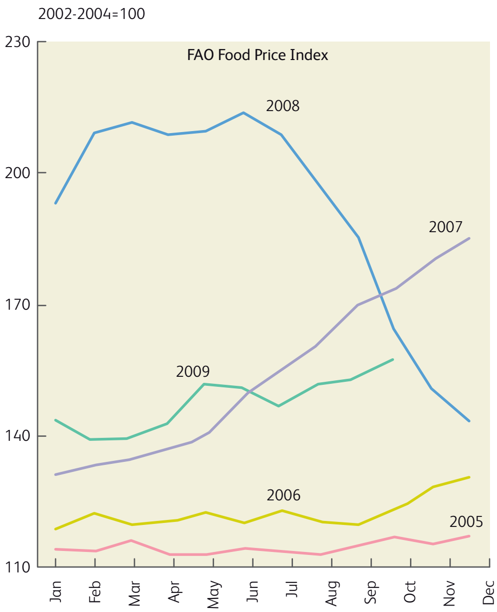
- US$3.00 on food;
- US$0.50 on household energy;
- US$1.50 on non-foods.

A 50% increase in food and energy prices means there is virtually nothing left over for other expenditures.[7] In practice people eat less: they have one less meal a day, women may reduce their food intake or children drop out of school.

Figure 5.1 depicts the dramatic trajectory of the 2008 food price crisis. Prices started to rise at the end of 2006, accelerated through 2007, reaching a peak in June 2008. Then they fell back to a low at the beginning of 2009.

In many respects the food price increase of 2008 was a classic price spike. First, a commodity becomes, or is perceived to be, scarce; second, prices rise; third, producers respond by producing more of the commodity and finally, prices fall. But while food prices fell at the end of 2008 they were still 20 % up on the 2006 prices and grew throughout 2009.

Figure 5.1 – The trajectory of food prices in 2008[8]



The drivers of hunger and poverty

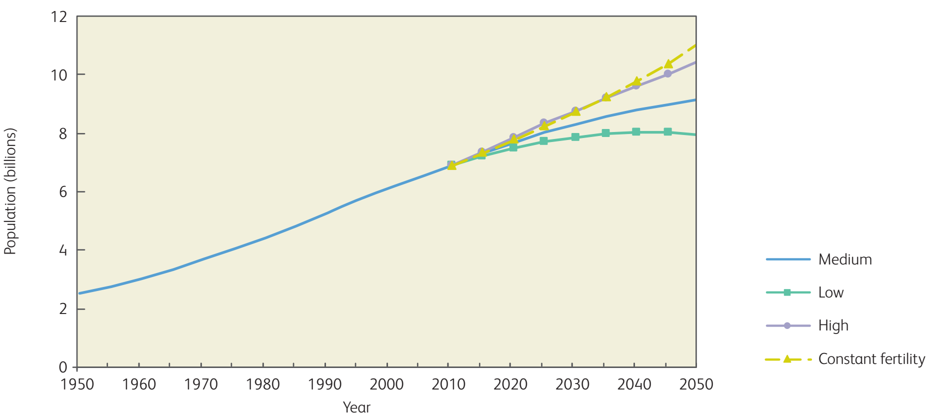
The food price crisis was not a simple transitory event.[9] It grew out of the underlying chronic crisis and that made it deeper and probably more persistent. It also raised awareness of the underlying drivers. These are not distinct processes. They may share common underlying causes and, most important, they feed on each other creating the hunger-poverty trap that was mentioned above.

The key drivers are as follows:

- ***Rising populations.***

  According to the latest UN estimates, the global population is set to rise to about eight billion, plus or minus a billion by 2050 (Figure 5.2).[10] Thereafter it may begin to stabilize and fall.

Figure 5.2 – Global population estimates – high, medium and low variants[10]



Inevitably this estimated rise in the population (from 5 billion now) will create an ever increasing demand for food. The International Food Policy Research Institute (IFPRI) model estimates that global cereal demand will therefore need to increase from about 260 million tonnes to over 450 million tonnes by 2050.[11]

- ***Rising per capita income and its affect on diet.***

Per capita incomes in countries in the Organisation for Economic Cooperation and Development (OECD) have increased five-fold (from US$5,000 to US$40,000 in current dollars) over the past 30 years. In South Asia and Sub-Saharan Africa they have more than doubled, although to only about US$1,000 (Figure 5.3).[12]

As incomes rise people eat more meat and dairy products, causing rapid growth in demand for feed crops, which raises prices (Figure 5.4). For example, among urban Chinese, meat consumption rose from 25kg to 32kg per person per year in the decade from 1996.[13]

With rising incomes, people buy more processed and higher value foods but not more raw agricultural commodities. Globally, meat consumption is expected to grow from 55 million tonnes to 310 million tonnes/year over the next decade. Meeting this demand will require feed grain usage to increase from about 50 million tonnes to about 640 million tonnes/year.[15]

Figure 5.3 – The steady, worldwide growth in per capita incomes over the past 30 years[12]

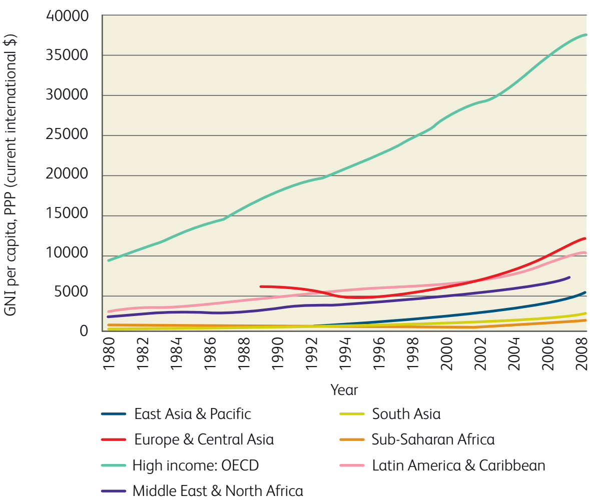
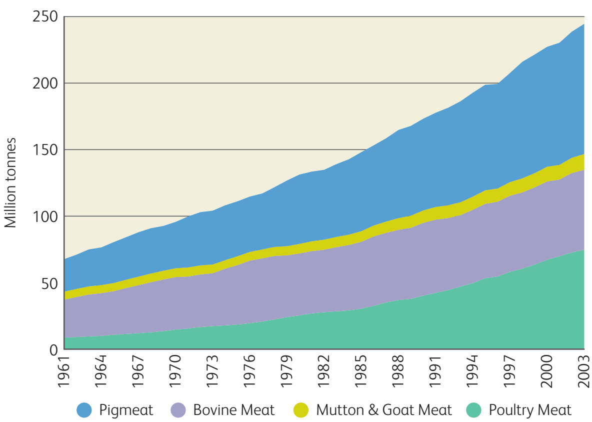


Figure 5.4 – The rise in meat consumption over the past 40 years[14]



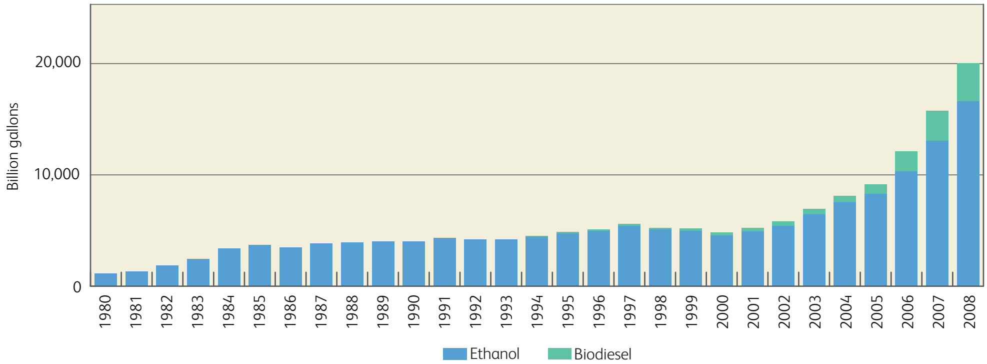
- ***Growing demand for biofuels.***

Growing crops to produce biofuels reduces land and production directed towards growing crops for human consumption, so contributing to rising prices. But how much of the 2008 price spike was due to the rapidly increasing demand for biofuels is strongly disputed (IFPRI estimates that demand for biofuels was responsible for 30 % of the rise in average grain prices).[16]

'The rapid increase in demand for, and production of biofuels – particularly bioethanol from maize and sugarcane – has had a number of effects on grain supply-and-demand systems. Expanded production of ethanol from maize, in particular, has increased total demand for maize and shifted land area away from production of maize for food and feed, stimulating increased prices for maize. Rising maize prices, in turn, have affected other grains.'[16]

What is not disputed is that biofuel production quadrupled between 2000 and 2008 (Figure 5.5)

Figure 5.5 – The rapid rise in biofuel production[17]



Moreover this rise is to continue. The proportion of US maize for bioethanol increased to 33 % of the expected corn crop in 2009-10 and it is set to continue rising to meet national targets. Challenging new targets have also been proposed for biofuels in Europe. In 2008, EU members agreed that biofuels will constitute 10 % of transport fuel in the EU by 2020.[18]

- ***Oil and fertiliser prices.***

Rising oil prices were one of the key elements of the 2008 food price spike. Indeed their rise was a precursor of the food price increase. The effect was, and still is, felt through the demand for biofuels together with the increased costs of transportation. This affects both agricultural input and output prices, and in particular the production, transportation and costs of fertilisers.

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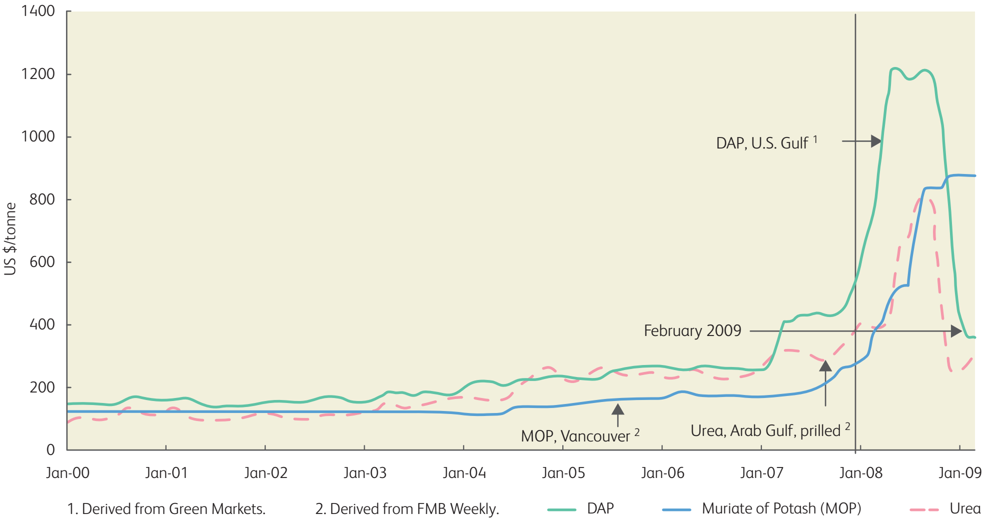
Figure 5.6 – Sweet potatoes are grown and consumed extensively in Sub-Saharan Africa

One of the biggest fertiliser price increases was in diammonium phosphate (DAP), a commonly used source of nutrients in developing countries (Figure 5.7). It rose nearly six fold in early 2008, due to the energy prices involved in the production of the ammonium, and because of shortages in both sulphur and phosphate, key elements in the manufacturing process. The price has since fallen significantly but, fertiliser prices are above 2006 levels and are likely to remain at this level.

Estimates of world phosphate reserves and the availability of exploitable deposits vary greatly. High-grade phosphate ores, particularly those containing few contaminants, are being progressively depleted whilst production costs are increasing. One review concludes that within a time span of some 60 to 70 years about half the world's current economic phosphate resources will have been exhausted.[19]

Figure 5.7 – The rise and fall of fertiliser prices in 2008[20]



- ***Increasing water and land scarcity.***

The amount of arable land worldwide divided by the total population has halved to about 0.2 ha over the past 40 years.[21,22] At the same time large areas of land are being degraded as a result of erosion, loss of fertility and desertification. Similarly, water is in short supply (see Chapter 7).[23] Many river basins do not have enough water to meet all the demands. About a fifth of the world's people – more than 1.2 billion – live in areas of physical water scarcity. Rivers are drying up, groundwater levels are falling, freshwater fisheries are being damaged, and salinisation and water pollution are increasing. Growing water scarcity and declining land for crops will make agriculture less productive and food more expensive.

- ***Impact of climate change.***

The 2008 price spike was not a result of climate change, although there is some evidence that the catastrophic drought in Australia – the worst for over 100 years – was made more severe in its effect on crop yields due to higher evapotranspiration resulting from higher land surface temperatures.[24-26] In Chapter 9 we will show how future climate change will have an increasingly adverse effect on food production.

- ***The slowing of productivity increases.***

  Growth in grains and oilseeds production has been slowing, from an average of 2.2% in the period 1970 to 1990, to an average of 1.3% since 1990.[27] Growth in global aggregate yield averaged 2% between 1970 and 1990, but declined to 1.1% between 1990 and 2007. The factors mentioned above have contributed to this slowed growth. In addition, the recent decline in agricultural research and development, and the fall in the rate with which plant breeding has increased productivity of some staple crops, have also had an impact.

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Figure 5.8 – A farmer in northern Vietnam sifting seeds

- ***Price fluctuations.***

  Finally, food commodities are notoriously subject to severe price fluctuations. It is a phenomenon that has long been recognised and was the rationale for establishing government purchase and storage schemes such as the various editions of the US Farm Bill and the European Common Agriculture Policy (CAP) which aim to smooth the fluctuations. In the 2008 price spike some argue that there was a strong element of speculation. Certainly the perception of shortage was particularly acute in the case of rice, for which only a small proportion of the total harvest is normally traded. This resulted in the Philippines buying large quantities at high prices.

As Joachim von Braun has argued the interactions between these drivers were intensified by the linkages between social unrest and food riots that spread from country to country.[28] Not only is hunger a cause of unrest and conflict but so is the fear of hunger.

Hunger and technology

Some conclude from these events that problems of food security can be primarily, indeed exclusively, solved by resorting to appropriate social and economic policies. They often quote from Amartya Sen's study of the great Bengal famine of 1942 to 1944. He stated that *'Starvation is the characteristic of some people not having enough food to eat. It is not the characteristic of there not being enough food to eat.'* This implies that we do not need to invest in food productivity or in the technologies this requires.[29] Globally it may well be true that there is enough food for all if it were evenly shared. But this would suggest large and continuing shipments of free grain that would create a lasting dependency and hamper the creation of indigenous production and markets.

In practice, the causes of hunger vary from place to place. In some situations the principal factors may be growing demand for, and lack of access to, food. In others poor yields, highly destructive pests, diseases and weeds may mean there is insufficient food, even if it were evenly shared.[30,31] Yet, as the Green Revolution demonstrated, greatly increasing food production had a transformative effect on Asia's food security, as Amartya Sen recognised.[32] Appropriate social and economic policies are critical, as is the provision of secure rights to land and water. But equally there is a need for enabling technologies. Sen emphasised that one of the entitlements of poor people is access to technologies.[33] The challenge is illustrated by the conditions under which a woman farmer, such as Mrs. Namarunda, who represents a composite of situations existing in Africa, struggles to feed herself and her family (Box 5.1, page 126).

Box 5.1 A one hectare farm in Kenya[34]

Several years ago, Mrs Namurunda's husband died from a meningitis infection. Her eldest son inherited the family farm, a single hectare running up one side of a hill, in the Siaya district near Lake Victoria. The soils are moderately deep and well drained, but they are acidic, highly weathered, and leached. Mrs Namurunda's first son married and moved to Nairobi, where he is a lorry driver and has children of his own. Her elder daughter also married and now farms near her husband's village, closer to the Tanzanian border. Mrs. Namurunda was left on the farm – still officially owned by her absent son – with four younger children and the responsibility to produce food, fetch water, gather fuel, educate the children and take care of the family. But shortages of almost everything – land, money, labour, plant nutrients in soil exhausted from many years of continual crop production – mean that she is often unable to provide her family with adequate food. The two youngest children in particular suffer from undernourishment and persistent illnesses.

Like many others in Africa, Mrs Namurunda's farm provides an "insecure" livelihood and her family does not have food security. Fertiliser is too expensive so she starts each growing season with a maximum potential harvest of only about two tonnes from mixed cropping on her one hectare of land.

To survive, her family requires a harvest of about one tonne, so if everything goes right and the maximum harvest is achieved, it would be sufficient to meet their needs and to generate a modest income. But, during the course of every growing season, she faces innumerable threats to her crops which reduce her yields. Weeds are her most persistent and pervasive problem. It takes 40 to 50 days of weeding each crop, by her and the children, to keep the weeds under control. Her staple crop, maize, is attacked by:

- Streak virus, where leaves develop long, white, chlorophyll-depleted lesions;
- The parasitic weed Striga, which sucks nutrients from the roots and poisons its host;
- Boring insects, which weaken the stem;
- Fungi which rots the ears that do develop, before and after harvest.

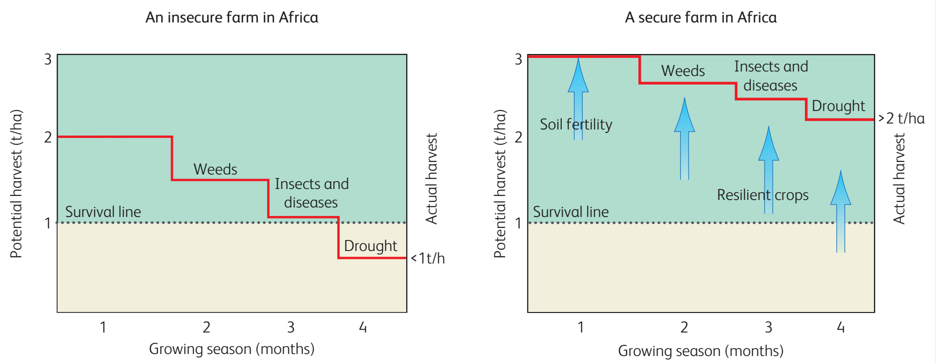

Figure 5.9 – A harvest on an insecure and a secure farm[34]

Mrs Namurunda has tried growing cassava as an "insurance crop." But it, too, was attacked, first by mealy bugs and green mites, exotic pests from Latin America, with no indigenous predators in Africa. Then it was totally devastated by a new super-virulent strain of African cassava mosaic virus that originated in Uganda, carried to Kenya by its white fly vectors.

The banana seedlings she obtained from neighbours were already infected with weevils, nematodes and the fungal disease Black Sigatoka (another import from Latin America) when she bought them. Her beans, which are intended as a source of protein for the family and nitrogen for the soil, suffer from fungal diseases that rot the roots, deform leaves, shrivel pods and lower nitrogen fixation. She also faces drought at some time during the growing season that again reduces crop yields. At the end of each season, what she actually harvests is usually less than one tonne. She and her children are often hungry, and there is no money for schooling or for health care.

It does not have to be this way for Mrs Namurunda and her children. Traditional, conventional or new platform technologies can provide answers, but they have to be accessible and affordable.

In this chapter we look at the ways in which science and innovation can develop technologies that go some way to mitigating the effects of the drivers of hunger. We begin with what has already been accomplished.

2. Past successes

The challenges highlighted by the food price crisis of 2008 must be placed in the context of the progress already made over the past 50 years in reducing hunger in the developing world. During that period the proportion of the global population that is chronically hungry has fallen from 37 % to 17 % and the total numbers from 1.4 billion to 1 billion.[35] We owe much of that to the Green Revolution, one of the great technological success stories of the 20th century (Box 5.2).

Box 5.2 The innovators of the Green Revolution[36]

Norman Borlaug was awarded the Nobel Peace Prize in 1970 for his work but sadly died in 2009. He was justly credited with being the Father of the Green Revolution. At the core of his innovations was the transfer to improved wheat varieties of a dwarfing gene – originally from Japan – by a speeded up, but conventional, process of plant breeding.

For nearly 20 years Borlaug worked with a team of Mexican and American scientists, in Mexico to improve local wheats. They achieved a great deal, especially in disease resistance, but were frustrated by the inability of the wheats to take advantage of high levels of fertiliser; the plants would 'lodge' and the ears rot. The new semi-dwarf varieties took up the nitrogen and produced yields of up to seven tonnes per ha.

In 1965, Norman Borlaug took the new seeds to India and Pakistan. In India M.S. Swaminathan became their champion; within ten years, average yields had more than doubled (Figure 5.10, page 128).

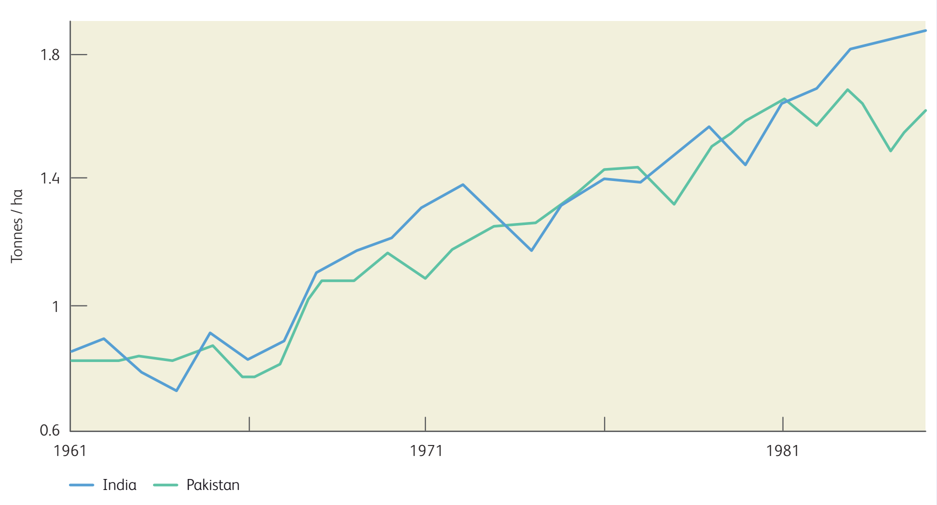

Figure 5.10 – The doubling of wheat yields in south Asia following the introduction of the new short-strawed wheat varieties in 1965[36]

Also in the 60s a similar innovation with dwarfing genes – originating in China – was applied to rice. The results were dramatic. In Indonesia rice yields doubled within ten years.[36] Again national innovators oversaw the transformations. Vo Ton Xuang's leadership took Vietnam from being a rice importing country in 1989, to the second largest exporter in the world by 1996.[37]

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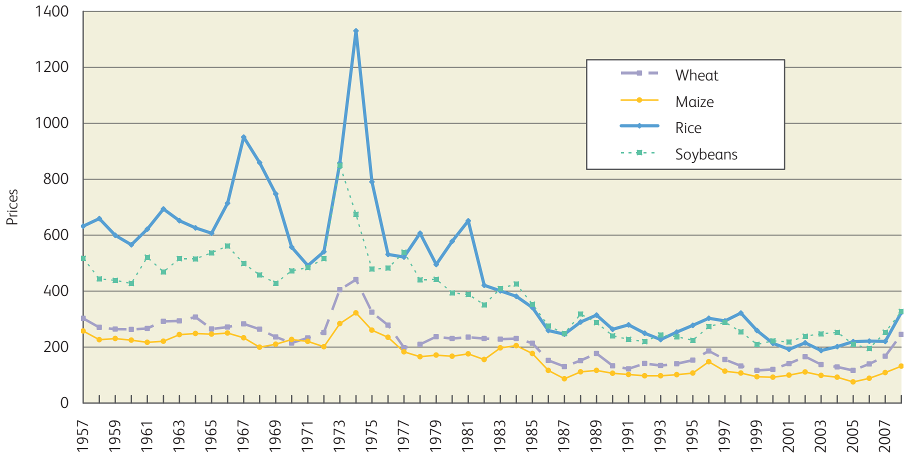
Figure 5.11 – Some of the Leaders of the Green Revolution (from left to right) – Norman Borlaug, M.S. Swaminathan and Vo Ton Xuang

Yields and production rose dramatically wherever new Green Revolution seeds were sown. By the end of the 1960s India and Pakistan were no longer dependent on foreign food aid. Food production began to outstrip population growth and the prices of the staple cereals fell progressively in real terms, benefiting both rural and urban consumers (Figure 5.12).

Figure 5.12 – After the oil price induced food price spike of the mid-70s cereal prices fell steadily[38]



The Green Revolution succeeded because it focused on three interrelated actions:

- Breeding programmes for staple cereals to produce early maturing, day-length insensitive and high-yielding varieties;
- The organisation and distribution of packages of high pay-off inputs, such as fertilisers, pesticides and water regulation;
- Implementation of these technical innovations in the most favourable agro-climatic regions and for those classes of farmers with the best expectations of realising the potential yields (notably Sonora in Mexico, the Punjab in India and Pakistan, and Luzon and Java in Southeast Asia).

But limits to the success soon became apparent. While the better placed farmers greatly benefited as did the labourers they employed, many small farms in less favourable environments missed out as did millions of the rural landless. There were environmental consequences too, arising from the intensive levels of inputs, particularly from heavy pesticide use in the early years.

Most important, while the benefits were apparent in much of Asia, the Middle East and Latin America, virtually all of Sub-Saharan Africa missed out. As a consequence there is still a great deal of hunger in the world (see Chapter 4). On present trends there is little likelihood of Sub-Saharan Africa halving the proportion of hungry by 2015; Ghana is the only exception.

But the challenges are not confined to Africa. Recent agricultural growth in India has also been disappointing (Box 5.3).

Box 5.3 Agricultural growth in India has slowed over the past 20 years

The early benefits to India of the new varieties and input packages and the investments in irrigation were built upon in the 1980s with a set of targeted investments that went beyond national food security and began to tackle poverty in the more marginal rural areas. By the end of the decade, growth in agricultural GDP per annum had increased from 1.4 %, at the beginning of the Green Revolution, to 4 %.[39]

Progress slowed in the 1990s, however, as a national fiscal crisis and a changing world political climate brought a wide range of structural adjustments. The previously over-valued exchange rate and import substitution policies were removed, and the Indian agricultural sector was opened up.[40] Private investments stagnated, public investment continued to decline, and growth slowed to around 2% over the decade, with rain-fed areas being hardest hit.[39]

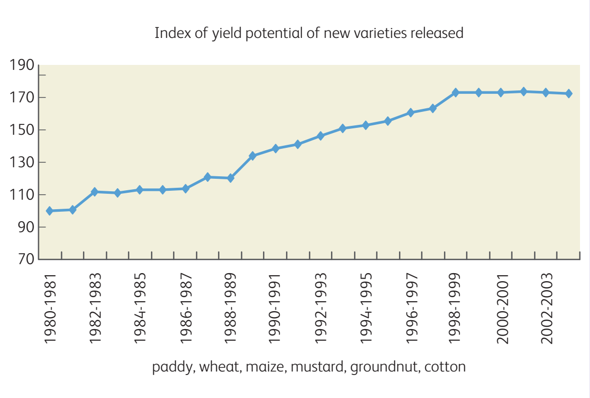


Figure 5.13 – The stagnation of yield growth in India as measured by the index of yield potential of new varieties of rice, wheat, maize, mustard, groundnut and cotton[41]

From 2000 growth slowed even further. Yield potentials stagnated and by 2004 per capita food grains production was back to 1970s levels (Figure 5.13).[41]

Indian farmers are increasingly vulnerable to declining water tables, ageing and poorly managed transportation and irrigation infrastructure as well as unstable markets. Inequality is also increasing in some areas, as richer farmers continue to make better use of the available technologies and overuse water resources.[39]

3. The need for a Doubly Green Revolution

Some have argued that what is needed is a repeat of the Green Revolution – a search for new technologies similar to those of the semi-dwarf cereal varieties that will deliver a quantum leap in yields and production. For a number of reasons this is unlikely to be an effective strategy.

The environments that were ideal for the Green Revolution varieties are already fully exploited. The poor and hungry live today in very different circumstances. Both in South Asia and Sub-Saharan Africa the challenge is to develop technologies that will deliver for relatively small farmers in more diverse, poorly endowed, risk-prone environments. This will require a variety of locally adapted technologies targeted on specific needs.

In brief we need a Doubly Green Revolution that:

> *'repeats the success of the Green Revolution on a global scale in many diverse localities and is equitable, sustainable and environmentally friendly.'*[36]

The goal is an agriculture that is:

- Highly productive – by 2050 we will need to have increased grain production by over 70% and it will need to be produced efficiently and cheaply;
- Stable – less affected by the vagaries of the weather and the market;

- Resilient – resistant or tolerant of stress or shocks, especially those generated by climate change (see Chapter 9);
- Equitable – providing food and incomes to the poor and hungry.

To produce this revolution we need to develop and implement new technologies and production processes that provide farmers with productive, stable, resilient and equitable farming systems (Box 5.4).

Box 5.4 The nature of sustainable agriculture

Agricultural systems, from the field to the watershed, can be characterised by four properties – productivity, stability, resilience and equitability. Each of these may be at high or low levels and typically in development they trade-off against each other. Thus, during the Green Revolution, high productivity was achieved at the expense of resilience and equitability. Sustainable agriculture aims to minimise these trade-offs and to produce as large as possible an overlap where all the properties are high.

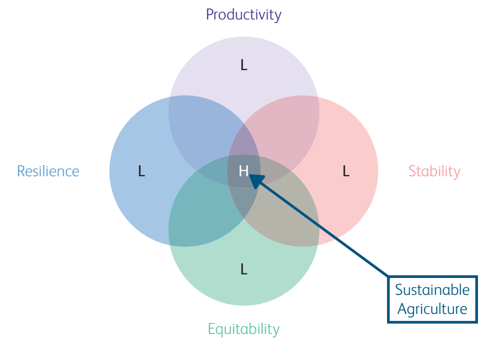


Figure 5.14 – Sustainable agriculture: minimising the trade-offs

The technologies for sustainable agriculture need to focus on five broad needs:

1. New crop varieties (and livestock breeds) that are more productive and of better nutritional quality;
2. Improved soil fertility and crops and livestock better able to use existing nutrients;
3. More efficient water use;
4. Better pest, disease and weed control without environmental damage;
5. Cropping and livestock systems that combine these qualities in ways that bring benefits to both small and large farmers.

As we discussed in Chapter 2 the technologies may be drawn from a wide range of sources. They may be:

- Traditional – encompassing everything from bird scaring to designing intricate home gardens;
- Intermediate – including treadle pumps for water supply and mixed cropping to reduce pests and increase nutrients;
- Conventional or industrial – comprising conventional breeding techniques and industrial agrochemicals;
- Advanced – including nanotechnology and the various forms of modern biotechnology.

In the following sections, we explore how science and innovation are contributing in these five areas.

4. Breeding for yields and quality

The Green Revolution resulted in dramatic increases in the yields of the main cereal crops. These translated into rising average national yields, for example in South Asia and China, but not in Sub-Saharan Africa (Figure 5.15).

Increasing yields

The yield increases in South Asia and China have partly come from plant breeding.[43] New varieties have been developed with a higher harvest index (the ratio of grain to total crop biomass), shorter stature and increased stalk strength that reduces susceptibility to lodging, so making them able to take up high amounts of nitrogen. Plants which mature earlier can exploit shorter growing seasons and make it possible to grow more than one crop a year in some environments. Annual double-crop systems with rice, wheat and maize are now the main cropping system where the soil, climate, and water environment are favourable. For maize and rice the development of hybrids has made a significant contribution.

But there is now evidence that the annual increase in cereal yields is declining.[43] As is evident from Figure 5.16 in South Korea, where all rice is produced with irrigation, the yields increased rapidly until 1980 but thereafter have plateaued at 80 % of the yield potential which has not changed. In Indonesia yields are continuing to rise because of increasing irrigation, while the yields in Thailand have remained low because 75 % of the rice is rain-fed on poor quality soils.

Figure 5.15 – Average cereal yields have increased steadily since the Green Revolution in China and South Asia but remained stagnant at 1 tonne/ha in Sub-Saharan Africa[42]

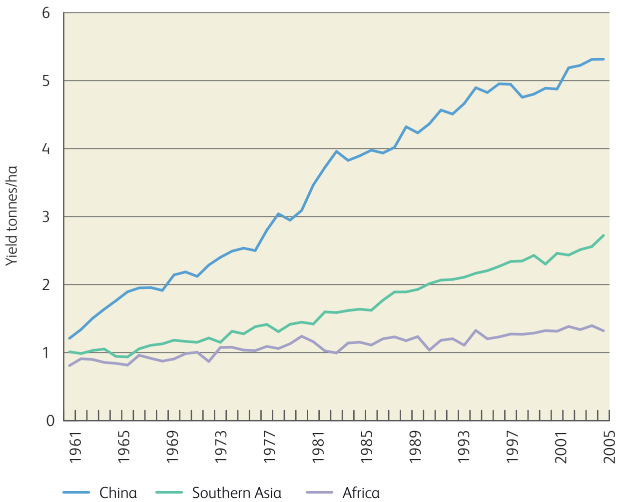
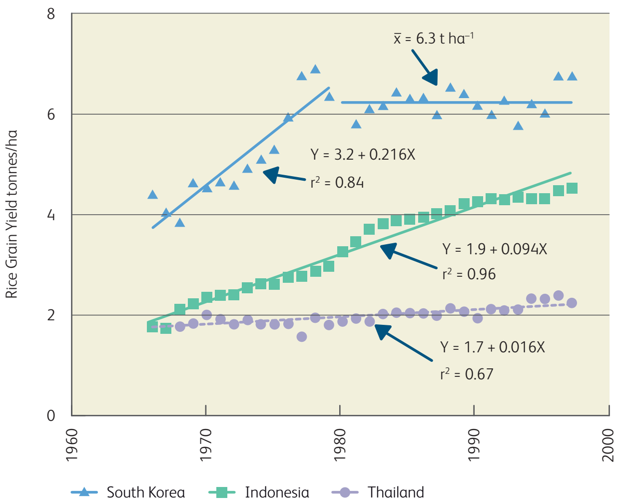


Figure 5.16 – Average rice yields in three Asian countries[43]



This has led some breeders to suggest we are reaching plateaux in yield potential for several crops (the yield potential is the yield under ideal conditions, i.e. when stresses are at a minimum) (Box 5.5). Kenneth Cassman argues that much of the gains over the past 30 years have been made through ‘a brute-force’ selection approach, and this may be increasingly unproductive.[43]

Table 5.1 Yield potentials of major cereals have plateaued at about the following levels. In the case of rice the potential is not much greater than in 1966

Crop	Potential in tonnes/ha	Comments
Rice	9 – 10	IRRI farm in the Philippines.[44]
Maize	16 – 20	Irrigated, yield contest winners, Nebraska.[44]
Spring wheat	10 – 11	Maximum yields in farmers’ fields.[45]
Winter wheat	12 – 15	Maximum yields in farmers’ fields.[45]

As in rice, there has been a similar slowing down in improving wheat yield potential. Investments have been targeted on traits such as quality and disease resistance rather than yield; further increases in yield may be possible with renewed efforts.[45] It has been argued that the high average yields of maize (about 9 tonnes/ha) attained in the US have been the result of the strong interest of the private sector in the crop (in contrast to rice and wheat).[46] Average annual US yields were about 1.5 tonnes/ha prior to the 1930s and only began to increase with the introduction of hybrids. Since then increasing yields have, in part, been due to plant breeding and in part due to improved agronomic practices.[47]

Hybridisation

The production of hybrid crop varieties has been one of the major successes of plant breeding over the past hundred years, but its full potential in the developing countries has yet to be realised.

Hybrids make use of the property of ‘hybrid vigour’ (or heterosis), where the decline in quality which comes from self-pollination, is overcome by crossing different lines of the species to provide an extra yield increment (Box 5.5). Often the more distant the relatedness of the crosses, the higher the heterosis. This property was discovered in maize some 100 years ago,[48] and has since been exploited across the developed world and, to a limited extent, in Asia and Africa.

Box 5.5 The steps in producing hybrid maize[49]

The superiority of hybrids over self-fertilised (inbred) plants and animals has been known for thousands of years, but modern hybrid maize breeding began in 1909, through the work of George Shull of the Carnegie Institute. Some of the first hybrids were bred by Henry Wallace, later to become Secretary of Agriculture, in 1923. Adoption took off in the US in the 1930s: in Iowa, the proportion of hybrid maize grew from less than 10 % in 1935 to well over 90 % only four years later.

The process is relatively straight forward:

1. Elite inbred lines are crossed;
2. Their progeny are then self-pollinated over five generations or so to find the best performing lines;
3. Some of the best, unrelated inbreeds are crossed to produce the hybrids which are tested in different environments over several years;
4. Each year the two best parents are crossed to produce the hybrid seed for sale.

In Kenya, for example, the first steps in hybrid maize production began in 1955, under the country's chief maize breeder, who decided to widen the genetic base by crossing an Ecuadorian line with a local improved variety.[50,51] In 1964 the new Hybrid 611 provided a remarkable 40 % yield advantage over previous varieties, and enjoyed a rapid uptake by both large- and small-scale farmers. This spawned what has been termed in Kenya the 'Maize Green Revolution', with continued increases in yields and spread of innovative hybrid varieties across the country from 1965 through to 1980 (Figure 5.17). The technological breakthroughs were supported by government policies which provided an extension programme, credit and subsidised inputs for smallholders, as well as a controlled export market.

But with the decline of support for public agricultural research through the 1980s, and pressure to reduce state subsidies and market support, the growth declined.[51]

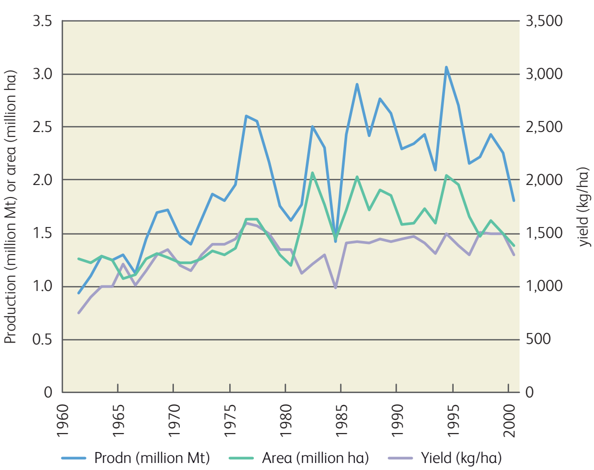
Elsewhere in the developing countries, hybrids are less common and yields are accordingly lower. In India over half of the planting is of open-pollinated varieties which cross at random and generate an average yield of only two tonnes/ha.

In Malawi a large-scale programme of subsidies for maize seed and fertilisers was introduced in 2005/6.[52] Farmers could choose from among the following:

- Their local landraces whose seed they keep from year to year;
- Open-pollinated (OPV) or composite maize – essentially mixtures of different varieties whose seeds can be re-used for at least three to four years without significant deterioration in yield;
- Hybrid maize – where the seeds need to be obtained and planted every one or two years to maintain high yields.

Yields under optimal conditions are three, five and eight tonnes/ha respectively for local, open-pollinated and hybrid seeds. Significantly, by the 2006/7 season

Figure 5.17 – Maize production in Kenya[50]



the farmers were predominantly choosing the hybrids, many thousand farmers for the first time. The result was a spectacular increase in total maize production from under two million to over three million tonnes for the country as a whole.

It is clear that wider adoption of hybrid maize will greatly increase yields. This is true for small farmers as well as large (in Malawi small farmers are readily producing five tonnes from a one ha plot sown with hybrid seeds and using adequate fertilisers). There is no fundamental reason why developing country maize yields should not approach those of the US.

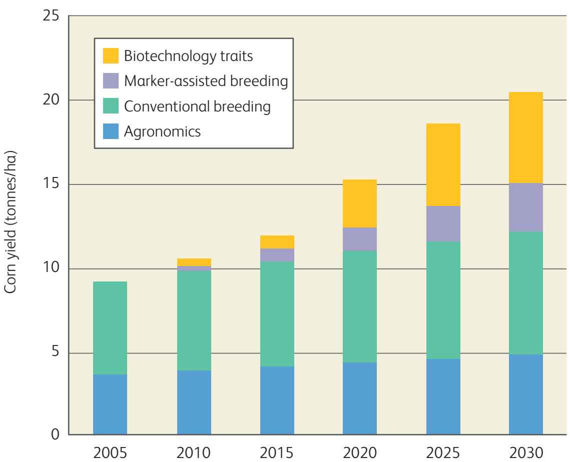
The same argument also applies to hybrid rices which have been developed more recently in China.[53] For some time there has been disappointing progress in improving the yields of tropical rices. But the new hybrids have a high yield potential when grown in tropical lowland environments.[54] They account for about 50 % of the rice area in China with average yields of seven tonnes/ha. Attention has now turned to the development of super hybrid rices with average yields over nine tonnes/ha and in some trials 12 tonnes being achieved. Adoption is beginning to occur in Vietnam, India, the Philippines and Bangladesh. There are impediments to further growth of hybrid rice varieties, including low hybrid seed production, high seed cost, and poor grain quality but these can be overcome.[44]

Beyond hybridisation

In the US breeding improvements, beyond hybridisation, have relied on marker-aided selection (MAS) (see Box 2.17 in Chapter 2) and the use of recombinant DNA engineering to produce genetically modified (GM) crops.

So far MAS has focussed on individual traits such as resistance to maize streak virus or that which enables the introduction of certain nutritive proteins in the grain (see below). Breeding for yield is more complicated because it is controlled by numerous genes. Nevertheless, MAS has demonstrated improvements in yields of maize and soybean in the US utilising traits for grain moisture and the prevention of stalk lodging.[55] Currently GM technologies increase yields by targeting the pests and weeds that reduce yields, but new generations of GM crops will soon be released in the US that have direct yield enhancing traits.

Figure 5.18 – Predicted relative contribution of agronomic methods and different breeding technologies to improving maize yields in the US[46]



Companies, such as Monsanto, that are intimately involved in the development of biotechnological approaches, believe that by 2030 approximately half the yield increases of crops such as maize will come from biotechnology (Figure 5.18).[46] In due course this could also hold true for the developing countries.

Improving nutritional value

Hunger is not only due to a lack of calories, but also a result of deficiencies in a range of proteins and micronutrients in the diet – sometimes referred to as hidden hunger. Most of these deficiencies can be improved by having a varied diet including meat, milk, fruits and vegetables in addition to cereals. Yet such diets are often not available or affordable for poor people and they have to rely almost exclusively on the staple cereals. This is particularly true of infants and young children where malnutrition is widespread in Sub-Saharan Africa and South Asia.

Perhaps surprisingly, most cereals and other staples are deficient in a number of proteins and other micronutrients. For instance, maize is deficient in the amino acids lysine and tryptophan which are essential for building proteins in the body. However, the capacity to produce these amino acids exists in the maize genome and only needs the right genetic background for expression. In this case, a suitable mutant has been found and this has been used in a long meticulous programme of conventional breeding to produce new high yielding maize with these amino-acids present.[56] Marker-aided selection is now being used to transfer these genes into a wide range of locally adapted maize in Africa.

Vitamin A

Another major deficiency is vitamin A (Chapter 6). While provision of supplements and fostering dietary variety are effective, they often do not reach the urban or rural poor.[57] Breeding beta-carotene, the precursor of vitamin A, into staple foodstuffs, for example sweet potato or rice, can provide a more stable and sustainable source at little or no extra cost. (Box 5.6)

Box 5.6 Breeding for vitamin A

Sweet Potatoes

This root vegetable is grown and consumed extensively throughout Sub-Saharan Africa. It can be grown in poor soil conditions, has few natural enemies, is highly tolerant of weeds, and provides a good source of energy and carbohydrates. The crop is often grown by women for both family consumption and extra cash. Sweet potatoes come in multiple varieties. The orange-yellow varieties are relatively rich in beta-carotene, but the white-fleshed, starchy types that have less of the compound, are traditionally favoured amongst African populations. Research is now focussed on breeding a variety with high beta-carotene levels that will be acceptable to African palates, are virus resistant and grow well in the local climate. Markers have been identified for high beta-carotene

Figure 5.19 – Women enjoying orange sweet potato

Figure 5.20 – Rice grains with and without beta-carotene. Golden Rice 1 was the first generation, Golden Rice 2 the second. (from left to right) Wild type, Golden Rice 1, Golden Rice 2

content and the first releases of improved 'biofortified' sweet potatoes were made in Uganda and Mozambique in 2007.[57-59]

The breeding has been conducted by scientists at the International Potato Centre in Lima, Peru as part of the CGIAR's HarvestPlus programme and implementation is being led by the Vitamin A Partnership for Africa (VITAA), formed by bringing together scientists with health and nutrition agencies, NGOs and private businesses. Together these groups are working with communities to explain the benefits of the new varieties and promote their uptake.

Rice

In Asia, and many parts of Sub-Saharan Africa, poor families consume rice as the basic staple of their diet and babies are often weaned on rice gruel. But the rice grain lacks beta-carotene; there is plenty in the leaves and stems, but none in the grain endosperm. And no amount of traditional breeding has been able to get it there (Brown, unmilled rice contains only minute amounts of beta-carotene).

Here the approach has been to find suitable genes elsewhere and to use recombinant DNA to insert them into a new variety of rice named, after its distinctive colour, 'Golden Rice.' (Figure 5.20).

Ingo Potrykus of the Swiss Federal Institute of Technology, and his colleague Peter Beyer of the University of Freiburg, first transferred two daffodil and one bacterial gene into rice to ensure the grain contained beta-carotene. The biochemical pathway leading to beta-carotene is largely present in the rice grain but lacks two crucial enzymes: phytoene synthase (*psy*) – provided by a daffodil gene – and carotene desaturase (*crt1I*) – provided by a bacterium gene.[60] In the greenhouse this transfer gave beta-carotene levels of about 1.6 μg/g, significant but not large. Subsequently, scientists at Syngenta have found new versions of the *psy* gene in maize; which when introduced to rice increased the beta-carotene levels to 31 μg/g, although this high level degrades slowly during storage.[61]

Given a conversion ratio of beta-carotene to vitamin A of 4:1, the new golden rice (Golden Rice 2) will be able to provide the necessary boost to daily diets, even after six months of storage.[61] Currently the new golden rice varieties are undergoing field and feeding trials and being assessed on bio-safety criteria.

5. Improving the productivity and quality of livestock

Livestock are frequently ignored in discussions of food security. The emphasis in agricultural policies tends to be focused on cereal grains and this is equally true of donor programmes and projects. Yet for the rural poor, livestock are often a critical element in their livelihoods. It is estimated that about 600 million people, or 70 % of the rural poor, depend on livestock.[62,63] For many communities in arid environments, livestock such as cattle, sheep, goats and chickens are the main source of food and income. Besides meat, cattle are a valuable source of milk and blood, traction and fertiliser for the fields. They also serve as a traditional means of banking, being sold when times are hard or to finance a special celebration.

Despite their obvious importance, there has been insufficient coordinated effort to improve livestock productivity in developing countries in the past decades. While livestock systems in industrialized countries have evolved into highly efficient and planned commercial enterprises, most production in the developing world still relies on small flocks or herds, often free grazing. According to IFPRI, '*although three-quarters of the world's cattle and two-thirds of the world's pigs, poultry, sheep, and goats lived in developing countries in 1993, those countries produced less than half of the world's meat and a third of the world's milk.*'[64]

One success story is the progress made from 1970 to 1996 in India during 'Operation Flood,' which revolutionised milk production and consumption in a way that benefited the poor. The 30 year project was a coordinated effort by India's National Dairy Development Board to better connect milk producers to consumers through the establishment of dairy cooperatives and a national 'milk grid'. Measures were also taken to increase the productivity of cattle by improving veterinary services, ensuring better feed and nutrition for the cattle, extending artificial insemination for breeding and the development of vaccines for diseases such as tropical theileriosis.[65]

Productivity in other areas is growing slowly, especially in Asia where a scarcity of land increases the pressure to improve efficiency of livestock production.[64] Traditional systems are also beginning to be squeezed in other regions as grazing land decreases, changes in crop production methods leave less residue for crop feed, and more cereals are required for feed, which are often imported.[64] Solutions to these challenges can come through better quality feed and nutrition, improved management of stocking densities and better awareness of the entire livestock-crop-environment system (Box 5.21 on crop-livestock systems).

Breeding also plays a role in improving livestock productivity by helping to find and incorporate traits which better address changes in demand for meat products, expanding industrialisation and climate change issues.[66,67]

Developing breeding programmes

Farmers have been selecting for useful traits in their herds for thousands of years, since the first domestication of animals. Cattle have been selected for such obvious characteristics as size, colour and the shape of their horns, sheep for their wool, chickens for the amount of eggs they produce and livestock of all kinds for the taste and quality of their meat. They also select for animals that are resistant to disease. This process, like conventional breeding in plants, can be slow.

Artificial insemination has been used for more than 50 years to economically and efficiently improve herds. The practice is slowly growing in the developing world, especially in Asia, in sectors such as dairy cattle in India.[64] Another improvement technique is cross-breeding with foreign or exotic species, such as crossing Kenyan dairy cattle with European breeds. This has resulted in some improvements in productivity, especially in yields of marketable products such as milk and meat. Yet, while taking traits from foreign productive animals can bring quick results, it is expensive and desirable traits of local animals, such as adaptation to the local climate and diseases, can be lost in the cross-breeding process.[68-70]

Advances in applied genetics, molecular biology and reproductive technologies are making it possible to more efficiently select for high quality characteristics, and to address the loss of genetic diversity among livestock worldwide. Since 1990, 300 out of 6,000 breeds identified by FAO have become extinct and many more are at risk, largely as a result of unplanned intensive selection and cross-breeding.[71] Traditional breeds, which have evolved over generations to be particularly well adapted to local conditions, are being lost. Here, genetic mapping and markers can be used to gain an understanding of the current state of diversity in various breeds. This information can be fed into the design of conservation and breeding programmes, making difficult choices such as the prioritization of sheep breeds in Ethiopia (Box 5.7) easier.[72,73]

Box 5.7 Conservation of sheep breeds in Ethiopia

Ethiopia is believed to have the largest livestock population in all of Africa, with the sector accounting for around 15 % of total GDP and contributing to the livelihoods of around 70 % of the total population. Sheep play a particularly important role, with a herd population of around 24 million, largely kept by smallholders, both in the cooler highlands (25 %) and the more arid lowlands (75 %). Despite their significant role, to date, there has been no coordinated national sheep breeding strategy.[74]

To help address this problem, researchers from the Agricultural Research Centre in Ethiopia, Wageningen University in the Netherlands and the International Livestock Research Institute (ILRI) recently teamed up to prioritise the 14 traditional Ethiopian sheep breeds. As criteria they used the breed's vulnerability to extinction, its contribution to farmer livelihoods (as ranked by the farmers) and its contribution to genetic diversity (based on a breed's uniqueness). Rather than just ranking the breeds by one of these criteria, the team aggregated the results to provide overall rankings (Table 5.2).

Breed	Contribution to diversity	Extinction probability	Average breed merit to farmers	Total utility	Conservation priority rank
Simien	0.4355	0.3	0.33	0.60	1
Gumz	0.1170	0.9	0.23	0.44	2
Adilo	0.0000	0.4	0.17	0.17	14

Table 5.2 – Extract from ranking table for Ethiopian sheep breeds

Rankings like this can provide a more scientific means of balancing the trade-offs between genetic conservation and present-day livelihood concerns, and can be used as a starting point for regional or national conservation plans.[75] Recommendations from the research team included:

- Supporting genetic improvement programmes to increase market competitiveness of indigenous breeds of lower productivity;
- Separating production zones to avoid indiscriminate cross-breeding;
- Implementing management strategies which conserve within-breed variation.

© Belay Duguma

Figure 5.21 – Horro Sheep in their centre of origin, Horro Guduru Wollega, Ethiopia

Efforts to better understand and map livestock genetic characteristics should be used to improve breeding programmes, and to help livestock owners decide whether to select from local or exotic stock, and where artificial insemination or other modern technologies are appropriate. National programmes also need to prioritise local needs for productivity, adaptability and genetic conservation, and find new ways of extending this information to local owners.

6. Improving the fertility of soil and its utilisation

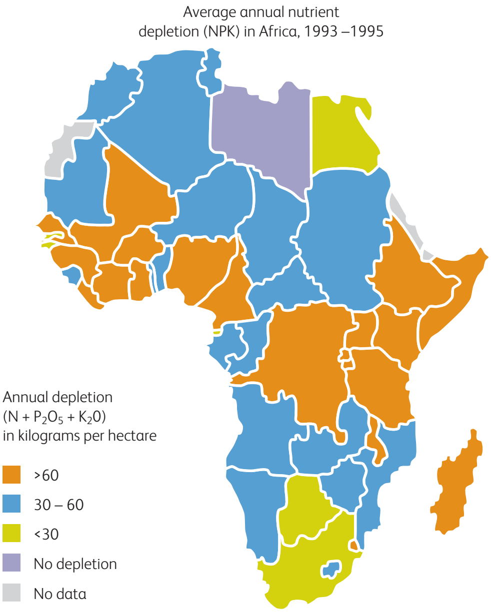
The provision, uptake and utilisation of nitrogen were critical to the success of the Green Revolution. In part this was due to the high application of inorganic fertilisers, but also because the Green Revolution lands were inherently rich in soil fertility. For example, a typical irrigated rice soil in Asia contains about 2,800 kgs nitrogen (N) per ha in the top 20 cms of soil.[76]

By contrast much of Africa's soil is derived from ancient granite rocks, which have been subjected to thousands of years of weathering and are therefore inherently low in plant nutrients. For example, the loamy sand and clayey soils of sorghum and millet plantations in central Mali, peak at around 20 and 40 kg N/ha respectively in the topsoil,[77] and sampled maize fields in Malawi contain 40 kg/Nha at the most.[78]

Whatever the original level of nutrients, agricultural activity can reduce soil fertility by depleting nutrients or contributing to soil erosion. Globally some 2,000 million ha of the Earth's land area is estimated to be degraded in one way or another.[79,80] 84% of the loss is due to water or wind erosion.[80] More than 80% of all degraded land is located in Africa, Asia, South and Central America.[43]

The net consequence is a continuous depletion of soil fertility. Most African countries lose more than 30 kg of nutrients (nitrogen, phosphorus and potassium) per ha per year (Figure 5.22). For some countries the figure is even higher: Rwanda was losing over 100kg of nutrients/ha/per year in the 1990s.[81]

Figure 5.22 – Most African countries are losing over 30 kgs of nutrients (nitrogen, phosphate and potassium) per ha per year[81]



Clearly part of the answer lies in significantly adding more inorganic fertiliser to the soils. In Africa, traditional fallow-based or rotational agriculture, which allowed soils to recover their fertility between cropping periods, has given way to continuous cropping without the application of fertilisers. On average, farmers in Sub-Saharan Africa (excluding South Africa) apply less than 10 kg of nutrients/ha, compared with 100 kg/ha in South Asia and 135 kg/ha in Southeast Asia.[82]

There is considerable evidence from African trials on farmers' fields that adding fertilisers will result in marked increases in yields.[83] Farmers in Malawi who are supplied with hybrid seed and adequate fertiliser can easily produce over five tonnes/ha on one ha plots, compared to less than one tonne using traditional methods.[84]

However, as indicated in Figure 5.7, fertilisers – such as diammonium phosphate – are now considerably more expensive and are only going to be affordable if technologies are developed that use techniques such as precise targeting to increase fertiliser efficiency. Far too often, extension systems advocate national fertiliser recommendations which may not be appropriate for local conditions.

One consequence of the high price of synthetic fertilisers, and the attendant environmental problems with their use in some parts of the world, has been to stimulate scientific research into making their use more efficient and into improving other, natural sources of soil nutrients, as has long been practised in organic agriculture.

Precision nutrients

In Chapter 2, we showed how farmers can substitute more selective placement of fertilisers instead of the widespread practice of broadcasting them. Urea super granules (USG), inserted in the middle of every four rice plants in Bangladeshi paddy fields, resulted in an extra tonne of paddy with a reduction of fertiliser by over a third.[85] Another simple but powerful selective approach is to apply a small and measured amount of fertiliser in the planting hole when the seeds are planted (Box 5.8).[86]

Box 5.8 Micro-dosing: using Coca-Cola bottle caps to apply fertiliser

Farmers in Niger have recently benefited from experiments to discover how to reduce the amount of fertiliser they need to use and still give the crops the necessary nutrients. While farmers in the area already knew well the benefits of fertilisers, most could not afford to buy the large amounts typically recommended, and therefore were not using them at all, causing yields to suffer.

To address this and to avoid the negative effects of over-fertilising on the environment, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), along with the FAO, the University of Hohenheim in Germany and the National Agricultural Research Institute of Niger undertook research to discover the amount and mixture which was optimal for individual millet plants, a technique known as 'micro-dosing.'

Figure 5.23 – Women working a field in the Sahel

Soil scientists and an estimated 5,000 farmers took part in the research and participatory trial of the idea between 1998 and 2000.[87] The result was a tailored fertiliser mix and measuring technique for the area. They found that using a mix of phosphorus and nitrogen fertiliser the dose for each plant was about six grams and could be measured out with a Coca-Cola bottle cap – a very easy item to obtain. This fertilising technique equates to using 4 kg/ha, three to six times less than used in Europe and North America, but still very effective.[86]

The practice has been credited with boosting millet yields by 50 % to 100 % in the Sahel, thereby helping to reverse a 50-year trend of declining yields and rising soil degradation.[86] Researchers are continuing to work with farmers to monitor trends in soil nutrients and yields and to fine-tune, and even further reduce, the amount of fertiliser used.

Better precision also depends on what is already in the soil. At a regional and national level, soil surveys can identify areas where fertiliser application is most needed. In Malawi the Rockefeller Foundation funded a nationwide soil and cropping survey that resulted in recommendations for over a 1,000 distinct regions.[88,89]

Finally, precision can be increased by the timing of application. While it is common to recommend fertiliser application at the time of sowing or planting this may not be the optimal time for crop uptake. Typically, in Asia, rice farmers make a relatively large initial fertiliser application followed by a single top dressing later. An experiment on 180 farmers' fields in six Asian countries showed that yields could be significantly increased by a relatively small initial application of prilled urea (the usual fertiliser) and two to three subsequent top dressings based on the readings from a chlorophyll meter. This produced an increase in the nitrogen recovery efficiency, from the 30 % typical of farmer's traditional practices, to some 40 %. On average yields rose by 500kg/ha, fertiliser use was reduced by 5 kg N/ha and returns were up by US$46/ha.[76,90]

Cropping systems

Productive soils are not only rich in nutrients but also in organic matter. This provides structure to the soil, improving stability, water-holding capacity and the ability of plants to absorb nutrients. It also prevents problems such as soil acidification that can result from inorganic fertiliser application. These functions not only improve plant health and drought tolerance, but lessen environmental impacts by reducing soil erosion and nutrient leaching into surrounding water sources.

Unfortunately many soils, and particularly those in Africa, are inherently low in organic carbon – and the amount declines with continuous cropping.[91,92] Even with high levels of organic carbon input, losses can be over two thirds of a tonne per ha per year.[93]

Crop residues and animal manure are important potential sources of both nutrients and organic matter for poor farmers. And, unlike synthetic fertilisers, they are renewable. But large amounts are needed to maintain soil fertility and to support increased production with improved crop varieties. A 10 tonnes/ha maize crop contains about 100 kg N/ha and at least this amount of nitrogen must be added back to the field to maintain fertility.[46]

Over much of Africa, crop residues, the mix of stalks and leaves – referred to as the stover – are insufficient in amount and nutrient value to maintain more than a very low level of grain yield. For example, reasonable yields of pearl millet in Niger are only obtained with the addition of the manure from transmigrant cattle.[94] Elsewhere organic matter has to be imported, often entailing high labour costs.

An alternative approach to renewable sources of nutrients and organic matter is to design cropping systems that incorporate nitrogen fixing legumes which can provide both organic matter and nutrients. These may be green manures, such as clover, sunn hemp and jack-beans that are incorporated in the soil at the end of their growth. Alternatively legume crops, such as cowpeas or groundnuts – that will also produce a yield – can be grown in rotation, or by intercropping or relay cropping along with grains. This second option requires farmers to carefully plan the timing and combination of their planting, so that the two crops complement each other and nitrogen sources are used as efficiently as possible. See Box 5.9 for an example.

Box 5.9 MBILI intercropping

In western Kenya a local NGO has been experimenting with methods of improving the traditional legume-maize intercropping used by farmers in the area. The Sustainable Agriculture Centre for Research, Extension and Development in Africa (SACRED-Africa) noticed that the second maize crop often failed due to insufficient late rains. It pioneered an approach which uses faster maturing maize varieties, mixed with higher-value legumes such as green gram and groundnut.[95]

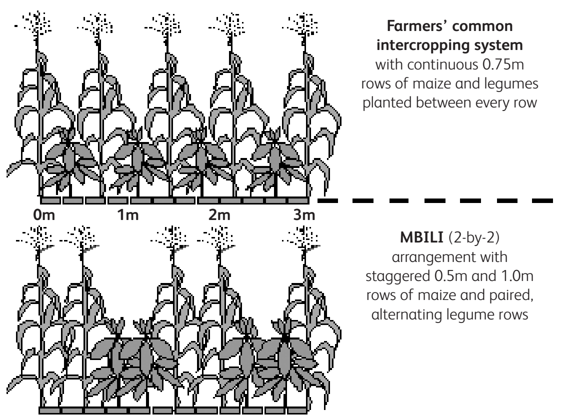


Figure 5.24 – MBILI cropping arrangements[96]

The system, known as MBILI (literally meaning 'two' in Swahili), consists of intercropping double rows of maize and legumes, allowing for better light and soil conditions within the understorey legumes, while maintaining the same plant populations, as shown in Figure 5.24.[96]

This provides several advantages, including higher efficiency of land use, disruption of normal pest cycles and the ability to grow crops with different light requirements.

By intercropping with high value legumes, the maize is able to take advantage of the nitrogen which is returned to the soil from the falling leaves and decomposing roots of the bean plants. The legumes can also be sold for a profit.[97] Studies over the past few years by SACRED staff and farmers have shown that planting in the MBILI arrangement can improve legume yield and total crop value by 12 % without the need for additional investment by the farmers or reducing the yield of maize.[96] Yields from the system can be over five tonnes of maize and over one tonne of groundnuts per ha.[98]

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Figure 5.25 – Women evaluating the MBILI trials

Breeding for nutrient uptake

An approach which complements efforts to increase soil fertility is to breed plants which are more effective at taking up and utilising nutrients. Box 5.10 explores this challenge and the progress made so far.

Box 5.10 Getting more from nitrogen

Breeding for nitrogen use efficiency has traditionally been neglected by plant breeders, because the processes and the genetics involved are extremely complicated. The desired trait is a higher nitrogen use efficiency, or NUE, defined as the yield of grain per unit of available N in the soil. Currently, average NUE in cereals production is only around 33 %,[99] and many believe there is a good potential for this to be significantly improved.

Unfortunately, NUE is a very complex trait. Nitrogen is taken up, transferred, stored and recycled through the roots, shoots, leaves and grains of a plant in response to a wide variety of triggers throughout its life cycle. Events such as leaf formation, flowering and grain filling require very specific regulation and control of the nutrient – a process which is managed differently in each individual grain crop species.[100]

Furthermore, most studies of nitrogen management have been conducted in high-N conditions. Plants behave quite differently when N is limited. Breeders also cannot select for high NUE in isolation, as they may risk inadvertently choosing cultivars which are weaker in other areas, such as yield potential or drought tolerance.[100,102]

Despite these challenges, some progress has been made. Breeders have been able to identify markers for the variability of NUE.[99] For example, scientists have discovered that the glutamine synthetase (GS) enzyme in maize not only plays a central role in N assimilation and recycling, but is also linked to yield and kernel size in both high and low N conditions.[101]

Future progress will depend on utilising tools such as micro-dissection, ^{15}N labelling, and more sophisticated crop simulation models to speed up discovery and also ease the transition of knowledge to the field.[100]

The alternative approach is to use recombinant DNA technology to incorporate in the major staple cereals a capacity to fix nitrogen that is similar to that in legumes (Box 5.11).

Box 5.11 Creating nitrogen fixing cereals

Legumes are capable of fixing nitrogen, taking it from its inert molecular form N_2, and converting it to nitrogen compounds such as ammonia, nitrate and nitrogen dioxide which can be used for plant growth. They do this through a symbiotic relationship with rhizobial bacteria that live in root nodules.

Figure 5.26 – Nodules form spontaneously in the absence of rhizobial bacteria on a root through removal of an inhibiting factor in the signalling pathway[104]

Unfortunately, the task of putting this capacity in cereal crops is considerable. Some 17 genes code the enzymes involved in nitrogen fixation. Since these genes, as well as the genes necessary for nodule formation, need to be transferred, the process is complex and its realization will be costly. Furthermore, there is an energy cost in fixing nitrogen. It is estimated that the amount of energy required to fix 150 kg of nitrogen per hectare could reduce wheat yields by 20 % to 30 %.[100]

While these challenges have made progress difficult, a few interesting discoveries have been made along the way. Scientists in Brazil have found that while the N-fixing bacteria *Gluconacetobacter diazotrophicus* occurs naturally in the roots, it is also present in the stems, leaves and trash of sugar cane and other tropical grasses growing in low-fertility soils. However, these occurrences are not widespread, and only seem to take place in low-fertility soils, where particular plant species have evolved to grow in the absence of fertilisers. Most modern varieties have evolved to make use of added fertiliser, thus minimising the potential for developing nitrogen fixing associations. For this reason, scientists may look to more ancient germplasm for breeding programmes in the future.[103]

Recently, work by scientists in Giles Oldroyd's laboratory at the John Innes Centre in Norwich, UK, has led to an important breakthrough. They managed to identify the genes which trigger the formation of nodules in legumes, and use this knowledge to induce the formation of nodules in the absence of the bacteria (Figure 5.26).[104]

While still a distant prospect, this could be an important step in transferring nodulation, and ultimately creating nitrogen fixing cereals.

7. Optimizing water use

The third key component of the Green Revolution was the massive investment in irrigation infrastructure that took place, mostly in Asia. Agriculture uses 85 % of fresh water withdrawals in developing countries, and irrigated agriculture accounts for about 40 % of the value of agricultural production in the developing world.[105] Today, much of Asia's grain harvest comes from the irrigated, annual double- and triple-crop, continuous rice systems in the tropical and subtropical lowlands of Asia, and from the irrigated, annual rice-wheat, double-crop systems in northern India, Pakistan, Nepal, and southern China.

However, many of these areas in Asia, the Middle East and North Africa are now maintaining irrigated food production through unsustainable extractions of water from rivers or the ground.[106] In China the groundwater overdraft rate exceeds 25 % and it is over 56 % in parts of northwest India.[107] Much of this excess is driven by subsidized or free electricity. Sub-Saharan Africa has large untapped water resources for agriculture. Only 4 % of cultivated land (5.3 million hectares) is irrigated, of which 70 % is in Madagascar, Nigeria and Sudan. The potential exists to bring an additional 20 million hectares of land under irrigation but, so far, technical, financial and socio-economic constraints have slowed this expansion. At the same time, almost a quarter of the African population live in water-stressed countries, and the proportion is rising.[106]

There is considerable room for improvement in existing irrigation practices; in most instances the major challenge is to improve the governance of irrigation systems by using a river basin or watershed approach.[108,109] However, the World Bank has pointed to a number of innovative technologies that can also improve the quality of irrigation services. It cites the potential of canal automation and satellite data to accurately measure water use in irrigation. Remote-sensing technologies can measure the amount of water from surface and groundwater schemes actually applied to the fields.[110] It also believes that moving from manually operated to automated channel control of irrigation, as applied in Australia, could be used in some developing countries.[111] Although such technologies require a substantial initial investment, they can be cost effective in the long run.[112]

Challenges to water management in rain fed systems

In many developing countries, particularly in Africa, the principle challenge for optimising water use in agriculture is to improve water capture and use by crops in predominantly rain fed systems. As with soil fertility, opportunities for scientific innovation range from enhancing traditional water capture technologies to improving crops through biotechnology.

In some cases, crop production can be greatly increased by simple, small-scale irrigation or water capture systems that either extend the growing system or make water available at times of stress. There are many traditional agricultural practices which attempt to do this, such as drip-irrigation techniques which deliver water directly to plants,[113,114] and the Zai system common in West Africa (Box 5.12).

Box 5.12 The *Zai* system

The *Zai* system is a traditional technology pioneered by farmers in the dry, sun-baked, encrusted soils of north-west Burkina Faso decades ago as a way to create more arable land. The technique has now spread throughout similar climates in the rest of Burkina and in Mali and Niger. Farmers first dig medium size holes or *Zais* (20 to 30 cms in diameter and 10 to 15 cms deep) in rows across the fields during the dry season. The *Zai* is allowed to fill with leaves and sand as the winds blow across the land. Farmers add manure to each *Zai*, which during the dry months attracts termites; these dig an extensive network of underground tunnels beneath the holes and bring up nutrients from the deeper soils. Stone earth bunds are constructed around the field, in order to slow run-off when the rains come.[115]

When the rains arrive, run-off is captured in the *Zais*. Sorghum or millet seeds are sown in the holes where the water and manure are now concentrated. Water loss through drainage in the

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Figure 5.27 – *Zais* in the sandy soil of Niger

often sandy soils is limited by the manure, and deep infiltration is made possible by the termites' porous tunnels. Thus, even in the drought-prone environment of the Sahel, sufficient water capture is ensured.[116]

Farmers have consistently reported greatly increased yields using this technique. In a study done in Bafaloubé, Mali, sorghum yield increased by 80 % and 168 % in 2000 and 2002 respectively, while millet yields increased by 83 % in 2001 and by 111 % in 2003.[117] The labour required to build the zais in the first year is quite high, but after that farmers may reuse the holes, or dig more between the existing ones. In many cases, after around five years the entire land surface will be improved.

One of the greatest recent successes in water and soil management has involved the substitution of a long-standing conventional technology, soil cultivation, with zero-tillage regimes in both developed and developing countries. Cultivation processes, especially use of the plough, can be implicated in high levels of both soil erosion and water loss. There is now a range of no- or minimum-tillage systems in development and use, that are grouped under the generic name of Conservation Agriculture, discussed further in Chapter 9 (Box 9.12).

Parallel to research into improved water capture and retention in crops, has been a growing interest in breeding plants which are more water efficient, and particularly drought tolerant. While some argue that increased infiltration and reduced run-off will have much greater impact on crop yields than can be expected from genetic improvement,[43] breeding for drought tolerance has achieved some success to date. It is of growing interest because global warming will cause some regions to become too dry for the staple crop varieties currently grown there (see Chapter 9).

8. Better pest, disease and weed control

The fourth main challenge to improved production is the collective deleterious effects of numerous pests, diseases and weed species on crop and livestock production. Some of these are particularly devastating. In many respects they are analogous to the great killer diseases of humans such as HIV/AIDS, malaria and TB. Indirectly they are responsible for a great deal of human mortality and morbidity. Like human diseases they often display the same capacity to outwit human attempts at their control. Box 5.13 details some of the more recent crop pest outbreaks in Africa.

Box 5.13 Some recent pest outbreaks in Africa

- **Cassava Mealybug** – This South American insect feeds on cassava shoots, reducing growth and tuber size. It was introduced accidentally into Africa on cassava breeding material in the 1970s, and spread, in only a decade, across the entire African cassava growing region, causing widespread suffering. The pest caused yield losses of up to 60%. It was finally suppressed by an African-wide biological control programme costing US$34 million. This proved a good investment, potential losses to African farmers from this single pest, discounted over 40 years, have been estimated at US$8 billion to US$20 billion.[118,119]

- **Cassava Mosaic Virus** – A new and highly virulent strain of this indigenous virus appeared in Uganda in 1988. The virus grew to epidemic proportions between 1989 to 1999, causing the loss of an estimated 60,000 ha. of cassava, equivalent to over 600,000 tonnes (US$6 million) of fresh cassava roots in the country. There were massive food shortages: in 1994 an estimated 3,000 people died of starvation as a result of famine caused by the plant disease epidemic. All the local varieties (over 500) were eliminated because they were highly susceptible.[120]

- **Banana Xanthomonas Wilt (BXW)** – This disease appeared in the Mukono district of Central Uganda in early 2000. It spread throughout the country and has since covered the Great Lakes region of Eastern Africa. It is estimated that the recent spread of BXW within Uganda will have an economic cost, borne by smallholders, of US$4 billion by 2010, and an even greater impact on household livelihoods.[121,122]

- **Coffee Wilt Disease** – This disease was first reported in Africa in 1927 and there have been periodic outbreaks in various regions. An outbreak in the Democratic Republic of Congo (DRC) in the 1970s, associated with abandonment of coffee plantings, spread into Uganda in the 1990s. In Uganda, smallholder income declined by up to 50% and losses in 2003 were estimated at US$9.6 million.[123]

- **Wheat Stem Rust** – A new strain of this fungus, Ug99, appeared in Uganda in 1999 and has since been detected across East Africa and the Middle East, reaching Iran in 2007. Kenya wheat areas suffered severe losses in 2007: field trials have shown Ug99 to cause yield losses of up to 80%. The predicted cost of a 10% loss in areas immediately at risk is estimated to exceed US$7 billion (See Box 5.16).[121,124]

At the time of the Green Revolution the most widely used approach to pest and disease control in crops was to use synthetic chemical pesticides. These were often effective, at least in the short term, but in the long term, some products made many pest problems worse.[125] Excessive or inappropriate use of pesticides often led to pesticide resistance in populations of pests, diseases and weeds. At the same time, insecticides, and some fungicides, eliminated important predators and parasites of pests and diseases. The loss of this natural control was not immediately recognised. In the case of the brown planthopper on rice (Box 5.14), farmers were surprised to see a resurgence of pest populations after spraying, due to the elimination of their natural enemies. Growing pesticide resistance and pest resurgence led farmers to apply more pesticides. This exacerbated the situation, leading to "pesticide treadmills". The growing costs of pest control, in the face of falling yields, began to make production unsustainable. In addition to these agricultural effects, there were also significant human health problems arising from pesticide use.[126,127]

In response to these pesticide-related problems, integrated pest management (IPM) was developed. IPM aims to control pests, diseases and weeds through a combination of appropriate, selective and sustainable methods. Usually, this meant a reduction in the reliance on chemical pesticides and a move to natural, sustainable methods of pest management, including reliance on natural enemies of pests and on traditional methods such as intercropping. Observation of pest populations over the season allowed farmers to restrict pesticide use to situations where pest abundance was damaging crops and yields. One of the earliest applications of IPM was to control cocoa pests in northern Borneo,[128] but the first large scale use of IPM on a staple crop was for the control of the insect pest brown planthopper that attacks rice (Box 5.14).

Box 5.14 IPM and the rice brown planthopper: science and farmer empowerment

In 1974, only a few years after the fertiliser and pesticide intensive Green Revolution planting programmes began, outbreaks of the rice brown planthopper, *Nilaparvata lugens*, started to occur in Indonesia. This sucking insect was, previously, a very minor pest but it soon spread throughout the rice growing areas of Asia. The initial response was to draw upon plant breeding and pesticides. New varieties resistant to planthopper quickly lost their resistance.[129] And government pesticide subsidies led to farmers becoming stuck on "pesticide treadmills," where they were continually paying more and more for chemicals which delivered less benefit.

There were many scientific theories about the cause of planthopper outbreaks, including: indirect stimulation of plants by pesticides, emergence of pest resistance to pesticides, and development and migration of new, virulent pest strains. In the 1980s, scientists at the International Rice Research Institute (IRRI) demonstrated that pesticide use caused planthopper outbreaks by killing predators, such as spiders, which fed on the pest.[130] Predators sit on plant surfaces and standing water and are highly exposed to sprays. They reproduce slowly, so just a few sprays can eliminate them from fields for long periods. The planthopper, by contrast, spends much of its life protected inside or under rice plants. It reproduces rapidly, so it can recover quickly after a spray, particularly in the absence of predators.

An IPM programme was developed which involved reducing pesticide use and recognising and conserving predators. Its implementation, however, faced opposition from entrenched government dependency on pesticides and the influence of the pesticide industry.

An FAO-supported programme identified that delivering IPM messages via national extension systems would not bring rapid change, and they embarked upon an ambitious plan for direct training of farmers through adaption of methods developed for participatory, community health programmes.

Figure 5.28 – A brown planthopper colony on rice stems

The 'farmer field school' approach developed by Peter Kenmore, was based on three principles to be conveyed to the farmers: (1) grow a healthy crop, (2) observe fields weekly, and (3) conserve natural enemies. In the schools, farmers participated in season-long programmes of experiential learning: designing, executing and interpreting experiments in their rice crops. As a result, they developed an understanding of crop, pest and natural enemy ecology and became experts in pest management in their own fields.

Farmers soon realised large economic benefits within a single season, because of reduced pesticide costs and sustained or even increased yields,[131] and they began to undertake their own IPM research. The concept gradually spread across Asia, Africa and Latin America and to other crops with intensive pesticide use, including, vegetables and cotton.[132]

Many years after the scientific research that led to the development of IPM, further ecological research has finally revealed why rice systems were so sensitive to pesticides in the first place. Work in Indonesia demonstrated that the flooding of rice fields creates an ideal environment for small insects and other invertebrates. Early in the season, spiders and other predators invade the fields to feed on these harmless organisms. When the rice grows and pests like the planthopper invade, the predators are already present in abundance and suppress pests before their populations can grow. But pesticide spraying suppresses this natural biological control system.[133]

Sometimes effective control can be brought about by agronomic means, in particular using interplanting with crops or other plants that deter or destroy the pest. A recent example has been the use of the legume *Desmodium*, interplanted to control the devastating weed *Striga*. This does however require skills and labour. An alternative is to use a herbicide but in such a targeted way that it is not only effective but has little if any environmental consequence (Box 5.15)

Box 5.15 The control of *Striga*

Striga, or witchweed, is a devastating parasitic weed that sucks nutrients from the roots of maize, sorghum and other crops. It infests as many as 40 million hectares of farmland in Sub-Saharan Africa and causes yield losses ranging from 20% to 100%. It affects the livelihoods of more than 100 million people, causing US$1 billion in annual crop losses.[134]

Two approaches to control *Striga* are being developed:

- The first involves intercropping maize with silverleaf, *Desmodium*, a legume which effectively controls *Striga* resulting in yield increases of two tonnes per hectare. Root exudates from the *Desmodium* cause suicidal germination of *Striga* seeds before they can attach to the maize roots. The intercrop also improves soil fertility and repels stemborers because of the odours that the plant releases. It is part of the 'push-pull' system which uses biological methods to combine *Striga* control with stem borer control.[135,136]

Figure 5.29 – The purple parasitic weed *Striga*

- *Striga* is also readily controlled by a herbicide, imazapyr, but this kills the crop. Recently, a mutant gene in maize has been discovered that confers resistance to the herbicide and is being bred into local maize varieties. The seed is then dipped into the herbicide before being planted. This kills the parasitic spores in the ground, allowing the maize to grow whilst minimising the environmental impact of the herbicide. Early trials are showing increases in yield from half a tonne per hectare to over three tonnes.[134]

Figure 5.30 – Maize interplanted with *Desmodium* to control *Striga*

Both these approaches are very promising but because of the scale and difficulty of the problem new technologies are urgently required. This is true of many of the other devastating pests, disease and weeds listed in Box 5.13, the ideal solution is to put resistance to these pests into the seed. It is by far the easiest and most convenient – and often the cheapest – approach, providing of course that the resistance is not too rapidly overcome.

There has been a long history of plant breeding for disease resistance, going back to the earliest days of modern agriculture. In many cases it is possible to find resistance in collections of varieties maintained in various parts of the world. At the present time there is a hunt on for resistance to an extremely serious disease, wheat stem rust, that threatens to devastate wheat in Asia (Box 5.16).

Box 5.16 The hunt for resistance to wheat stem rust

The causative agent of wheat stem rust is the fungus *Puccinia graminis*. The risk from this fungal pathogen is considerable. It is able to completely decimate wheat crops and infect distant fields via its windborne spores. Historically, the disease has been controlled through the propagation of resistant cultivars and the removal of the plants on which the fungus lives for the other part of its life cycle.[137] In spite of this, a novel strain of wheat stem rust, identified in 1999 in Uganda, was found to overcome both of the widely utilised rust resistant genes, *Sr31* and *Sr38*.[138]

This strain, known as Ug99 (Uganda 99), attacks the majority of the world's wheat varieties and therefore presents a serious threat to global food security. Since 1999 the spread of wheat stem rust has been alarming, with systemic cases reported in Uganda, Kenya, Ethiopia, Sudan, Yemen, and Iran.[139] The seriousness of these developments has led to the formation of the Borlaug Global Rust Initiative,[140] the Durable Rust Resistance in Wheat project at Cornell University[139] and the AGP-FAO Wheat Rust Programme.[141]

In the short-term the urgent need is to identify the small number of wheat cultivars that remain resistant to Ug99. However, the ability of the fungus to mutate and evolve means that protracted resistance will be unlikely. In the long-term there remains cause for optimism as researchers have discovered that rice is resistant to the entire taxon of rust fungi. The challenge is to identify the genetic information that confers the observed resistance of rice to rust and to successfully achieve its translocation into the wheat plant. This may enable the creation of a range of durable resistant varieties.[137,139]

The gene transfer technology is currently available to make this process feasible, but the severity of the current threat means researchers face a race against time.

This may prove successful and then the task will be to cross-breed the resistance into the wide range of existing mainstream varieties, maintaining their superior qualities while adding the resistance. However, in the case of many of the worst pests this approach will not work, either because no resistant genes are present in the crop genome (cowpeas in Africa are a good example[142]) or because they are not easily transferred. The alternative then is to utilise GM techniques.

In Chapter 2 we described the use of GM techniques for the control of cotton bollworm which has proven highly successful for millions of small farmers in China, India, South Africa and Mexico. One of the earliest forms of GM disease control was against the papaya ring spot, developed at

Cornell University, which saved the papaya industry in Hawaii and is being developed for countries in Southeast Asia. A current effort is targeted at controlling the Diamondback moth, a highly damaging pest of cabbages and its relatives, in tropical countries (Box 5.17).

Box 5.17 Developing GM crops for Diamondback moth[143]

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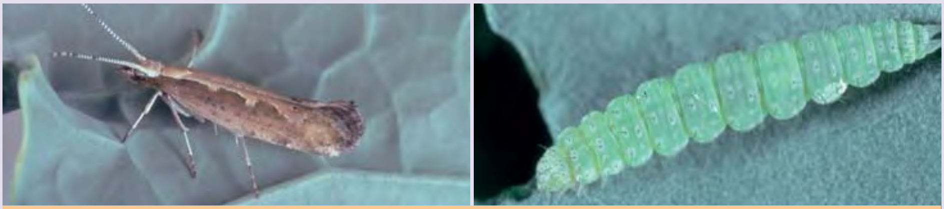

Figure 5.31 – Diamondback moth and its caterpillar

Cabbages, cauliflower, kale, mustard and other brassica crops are important food plants in developing countries. In India cabbage and cauliflower are grown by more than 20 million small-holders. But across Asia and Africa they are devastated by insect pests and particularly by the Diamondback moth caterpillar, *Plutella xylostella*, which can cause 90 % crop loss. Even when sprayed with insecticides, often every other day, with 12 to 24 applications normal in a three-month season, there can still be up to 35 % loss. The moth has developed resistance to almost all insecticides. One consequence of the heavy and frequent spraying is the serious health risk posed to farmers as well as to consumers and the environment.

The aim is to breed into cabbages a Bt gene that confers resistance to the Diamondback moth. Bt (the bacterium *Bacillus thuringiensis*), produces a toxin, a protein in the form of a crystal, which, when ingested, kills the caterpillar (see also Box 2.18 on Bt cotton). Because the protein toxin is so specific there is little or no effect on other wildlife and spraying of the bacterium against pests is approved in organic agriculture. One problem, however, is insect resistance to the toxin.

A new project to develop a Bt cabbage, managed through the public-private partnership Collaboration on Insect Management for Brassicas in Asia and Africa (CIMBAA), is introducing two different Bt genes. The caterpillars have not been widely exposed to these two proteins before and it is believed they cannot readily develop resistance to both toxins simultaneously.

It is intended that caterpillar resistant plants will be introduced within a full IPM programme (including the promotion of the use of natural enemies of the pests, and traditional, as well as technology-based practices), so maximizing their profitability, effectiveness and long-term sustainability.

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Figure 5.32 – Diamondback moth damage on an untransformed plant (left) and an undamaged Bt plant (right)

Control of major diseases of livestock

Livestock diseases have a serious impact on the livelihoods of farmers in developing countries. Many of these diseases are of global significance, e.g. foot and mouth disease of cattle and Newcastle disease of poultry. Strict international trade regulations restrict movement of animals from areas affected by disease. Outbreaks can be eradicated in wealthier countries but the same diseases are often endemic in poorer countries, causing substantial losses and limiting their capacity to trade. A focus of policy in wealthy countries on eradication has reduced impetus for research on vaccines, which would be of particular value in poorer regions where diseases are endemic. Financial constraints on farmers in developing countries also provide a disincentive for private sector investment in vaccines for tropical livestock diseases.

As we will see with human diseases in the next chapter, animal diseases can be managed by modifying the environment of the pathogen, or by targeting the pathogen directly. A good example of environmental management is vector control. Box 5.18 illustrates how innovative research on insect vector behaviour may help to reduce the impact of trypanosomiasis, a particularly serious disease of livestock in Africa.

Box 5.18 Selective control of tsetse fly in Africa[144]

Figure 5.33 – The *Glossina pallidipes* tsetse fly

Tsetse are large biting flies which live by feeding on the blood of animals and humans. They infest some 10 million km^2 of Sub-Saharan Africa, extending from Mali and Ethiopia in the north to South Africa and Namibia in the south. The flies transmit trypanosomes, tiny protozoa which cause trypanosomiasis, otherwise known as sleeping sickness in humans and nagana in cattle.

There are currently no vaccines against the disease and only a few drugs. Resistance against these is widespread and consequently one long-term solution would be to control tsetse. Effective control has successfully brought down infection rates in cattle. In Zimbabwe, cases have fallen from around 10,000 per year in the early 1980s, to less than 100 today. The methods used to control the flies have also evolved and are now more cost-effective, efficient and environmentally-friendly. Figure 5.34 shows the evolution of methods used in Zimbabwe during the 1980s.

In the early 1980s, the mainstay of tsetse control was the application of DDT to the resting sites of tsetse. This was supplemented by the aerial application of the highly toxic insecticide endosulfan. In the mid 1980s, in an effort to cut back on the amount of chemicals used, scientists began experimenting with the use of targets. These are cloth screens impregnated with insecticide and baited with artificial host odours, as tsetse flies are attracted to animals by vision and smell. They discovered that targets deployed at densities of just 4/km^2 could eradicate tsetse populations in a year.

In order to improve the effectiveness of the targets, scientists at the Natural Resources Institute (NRI) in London, in collaboration with Zimbabwean scientists, identified the pheromones which attract tsetse to their hosts. They also used GIS mapping and simulation techniques to study the relationship between the flies and the cattle and decide how to best deploy the targets.

To further reduce costs, researchers began looking at the option of treating the cattle themselves with insecticide. While it is costly and difficult to treat all of the cattle in a herd, they discovered that the flies predominantly attack the older and larger animals, and that for a typical herd, 80 % of meals are from 25 % of animals. Thus a big impact could be made by selective treatment.

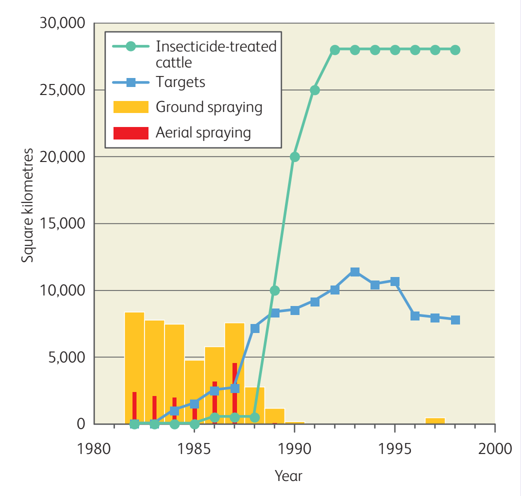

Figure 5.34 – Evolution of tsetse control in Zimbabwe[144]

Building on this, they looked at *where* on the animals the flies tended to land and bite. They found that 75 % to 99 % of tsetse feed on the legs or belly of cattle. So, by treating just the legs and belly of older cattle, very big impacts are made, costing less than US$1 per animal each year, and with less pesticides.

The other approach is to control the pathogen in the host, and this is usually done with vaccines or medicines. There have been very successful vaccination campaigns against animal diseases, including against the cattle plague, rinderpest, one of the most long-standing of livestock diseases. A highly contagious and lethal viral disease related to the human measles virus, rinderpest is thought to date back to the first domestication of cattle in Asia. It spread throughout Asia and Europe over the centuries, often through travelling military campaigns. It was introduced to Eastern Africa in the late 19th century.

Animals infected with rinderpest develop fever, discharges from the eyes and nose, erosions on mucous membranes of organs, diarrhoea and often death from weight loss and dehydration after 10 to 12 days. In its most severe form it is capable of killing 95 % of all animals it infects. The disease is spread when animals inhale aerosolized particles that contain the virus, or through contact with secretions from infected animals.[145] Cattle which recover, however, gain lifelong immunity.

A series of campaigns against the disease have now led to its global eradication (Box 5.19).

Box 5.19 The successful eradication of cattle plague[146]

The battle against rinderpest, described as 'the most dreaded bovine plague known,' has been long and hard-fought. Pandemics of the disease swept through communities in Europe, Asia and Africa over the centuries, bringing devastation similar to human plagues such as the Black Death. The disease served as one of the main motivating factors in the establishment of formal veterinary service institutions, such as the national veterinary colleges that were begun in the 1700s and the World Organisation for Animal Health in 1924.

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Figure 5.35 – Healthy cattle play an important role in rural livelihoods

The discovery in the 1880s that serum from a recovered animal could be used to develop a vaccine marked the start of coordinated rinderpest control. It was evident that the nature of the virus (there is only one serotype, no other carrier and the recovered animals acquire ability to confer lifelong immunity) would allow for the possibility of eradication. Rinderpest was successfully eradicated from Southern Africa by 1905 through strict legislation covering zoosanitary procedures combined with vaccination campaigns, and in Europe by 1928. The virus persisted, however, in pockets in South Asia and in Africa through to the 1990s.

In 1992 the idea of an internationally coordinated programme for worldwide eradication was conceived. The Global Rinderpest Eradication Programme (GREP) was launched through the FAO, set as a time-bound initiative to end in 2010. The GREP began a package of interventions including detection of existing cases and vaccination in infected areas with a transition to careful surveillance and national accreditations of rinderpest freedom. As of 2009, the GREP has pronounced that rinderpest is no longer circulating in domesticated or wild animals anywhere in the world, making it one of only two infectious diseases, along with smallpox, which we have succeeded in eradicating worldwide.

The eradication of such a damaging disease will bring many benefits to the lives of livestock owners in Asia and Africa, including security in their investments as well as added income from the lifting of trade restrictions. However, of perhaps even greater importance are the lessons learned during this widespread effort. While global eradication may not be appropriate for every disease, a number of both organisational and technical prerequisites for large-scale disease control have been proposed in a recently published paper. The technical elements include:

- A clear and evolving understanding of the epidemiology of the targeted disease;
- Safe, efficacious, affordable and quality-assured vaccines;
- A set of robust, validated laboratory diagnostic tools for agent detection;
- A world and regional reference laboratory network supporting the technology transfer to national diagnostic laboratories and technical fora for information exchange;
- Dynamic and innovative disease-control and eradication strategies based on epidemiological studies, adapted to local conditions and amended repeatedly;
- A clearly defined disease freedom accreditation process.

Solutions to controlling animal pathogens in developing countries will involve a mixture of conventional and new platform technologies. For instance, East Coast fever, which affects cattle across Eastern and Central Africa, has been the subject of many years of research at the International Livestock Research Institute (ILRI). Working with the Institute for Genomic Research in the US, IRLI has now succeeded in sequencing the genome of the protozoan parasite which causes the disease, *Theileria parva*. The sequencing, along with high-throughput immunological screens, has been used to identify potential vaccine antigens. The challenge now is to engineer these antigens into a sub-unit vaccine for the disease[147] (see Box 6.9 for a description of the main forms of vaccine). This would be the first experimental vaccine to protect mammals against a protozoan parasite, and findings from the research may help scientists make advances against related parasites such as malaria and TB.[148,149]

Meanwhile, in the course of this research, it has been observed that effective immunity can be conferred by infecting cattle with a mixture of live East Coast fever parasites and then treating them quickly with a long-acting antibiotic, which kills off the pathogen after the immune system has been stimulated. This mixture, known as the Infection and Treatment method, or the '*Muguga Cocktail*,' has been widely accepted by herders in East Africa. While not as elegant as the discovery of a vaccine, this approach is highly practical, and it is currently being scaled up with support from foundations and civil society organisations. Even here, continuing scientific research is needed to understand variation in the parasite, and hence the efficacy of control and immunization.[150,151]

The formation of a new public-private partnership, the Global Alliance for Livestock Veterinary Medicines (GALVmed), should help to progress work in this area.[152] The aim is to get existing diagnostics, medications and vaccines to farmers, as well as to understand better what influences farmer uptake of these products. The group will also be scaling up efforts to develop new preventatives and treatments which are safer, cheaper, more effective and protect against previously unpreventable diseases. New advances in biotechnology will also make it possible to develop vaccines which do not require refrigeration – a major benefit for rural small-holders.[153,154]

Attention is increasingly turning towards the need for integrated disease control packages, where multiple strategies, such as environmental control, community education, vaccination and treatment medications are applied together to control diseases with more complex transmission patterns. Box 5.20 (page 158) describes work to control the zoonotic tapeworm, *Taenia solium*, which infects both swine and humans.

Figure 5.36 – Sheep are an important source of food and income for many rural communities in developing countries

Box 5.20 Integrated control of pork tapeworm[155,156]

Figure 5.37 – A veterinarian in Africa

Taenia solium, or pork tapeworm, is a zoonotic tapeworm transmitted between pigs and humans, common in non-Muslim regions of Asia, Latin America and Africa. When humans eat raw or undercooked meat of pigs infected with *T.solium*, they ingest the larval form of the tapeworm, which then develops into the adult form in the human gut, causing a disease known as taeniasis. Those infected may be largely asymptomatic, although intestinal upset, nausea and diarrhoea often occur. They will however discharge segments of tapeworm in their faeces, and this is how the disease spreads. Pigs which have access to human faeces will ingest the eggs of the tapeworm, so completing the cycle.

It is also possible for the disease to be transferred directly from human to human upon ingestion of infected faeces. This can lead to a more severe form of the disease, cysticercosis, in which the larvae lodge in the infected person's organs. The most severe consequences resulting from lodging in the brain. Neuro-cysticercosis is one of the largest causes of adult epilepsy in poor, pig-keeping countries.

Due to the nature of transmission of this disease between humans and animals, and the prolonged incubation period of the disease in humans (from a month up to ten years), effective reduction in prevalence cannot be achieved without using a variety of measures. These can include some or all of the following:

- Preventing access of pigs to human faeces through housing or tethering;
- Education, marketing and infrastructure for improved hygiene and safe disposal of human faeces;
- Testing and treating infected humans;
- Testing and treating infected pigs;
- Meat inspection and processing or condemnation of infected meat;
- Education on appropriate pork preparation practices;
- Vaccinating pigs;
- Market-based incentives for producing cysticercus-free pigs.

The first large-scale elimination programme is now underway in the Tumbes Region of Peru, funded by the Bill and Melinda Gates Foundation. The intervention, informed by sociology, farming system science and epidemiology, integrates treatment, vaccination and advanced detection methods and is proving to be highly effective.

Zoonoses, or diseases which infect both humans and animals are of increasing concern, and we discuss these in more detail in Chapter 6.

9. Improved agricultural systems

All of these approaches to increasing yields, increasing nitrogen supply and uptake, conserving moisture and controlling pests are simply components that have to be woven into a total farming system. It is a task undertaken by farmers, large and small, on a day-to-day basis but it can be assisted by research into the structure and dynamics of farming systems themselves. Examples include the rice-wheat systems of Asia and many different forms of crop-livestock systems throughout the world (Box 5.21).

Box 5.21 Examples of contemporary innovative farming systems[157-159]

Rice-wheat systems

The Indo-Gangetic floodplain (IGP), extending across the Himalayan foothills of India, Pakistan, Bangladesh and Nepal, is one of the most fertile and productive agricultural areas of the world. The climate is sub-humid with a distinct wet monsoon summer season and a dry, cool winter season. With the introduction of the shorter-duration improved Green Revolution varieties in the 1960s, it became possible for farmers on canal irrigated land to grow rice and wheat in a double cropping pattern in one calendar year: rice in the summer and wheat in the winter. This led to impressive increases in per capita production, and irrigated rice-wheat systems remain the major source of marketed grain surplus in the area, helping to feed a growing urban population. Rice-wheat production systems now occupy 24 million ha of cultivated land in the Asian subtropics, with 13.5 million ha extending in the IGP alone. They cover about 32% of the total rice area and 42% of the total wheat area in these four countries.

In the 1980s, however, yield increases from these systems began to stagnate. Inappropriate fertiliser applications, scarcity of surface and ground water, and late and inefficient planting of the wheat rotation combined to challenge farmers in the area. Of particular concern were problems associated with the wheat sowing. Farmers were broadcasting seed into ploughed land and then ploughing again because of the need to deal with crop residue left over from the previous rice crop. This led to seed placement at many different depths and varying soil moisture levels resulting in variable germination. In addition, many farmers were planting the wheat crop too late, because too much time was being spent ploughing or dealing with rice residues.

In 1994, the Rice-Wheat Consortium was formed to try to restore high productivity to this important system, bringing together several CGIAR centres (CIMMYT, IRRI, ICRISAT, CIP and IWMI), the national agricultural research centres of the four countries, and a number other institutes. The group has introduced zero-tillage methods – with direct seeding of wheat into rice residues immediately following the rice harvest using an inexpensive and locally manufactured seed drill. They have also begun experimenting with bed planting, an idea picked up by Indian scientists when visiting the CIMMYT programme in Mexico. In this system rice and wheat are planted on top of a ridge and furrow system, leading to significant water and herbicide savings.

Through these innovations it is possible to improve yields of both rice and wheat while maintaining good soil quality, leading to extremely high productivity and efficient use of the improved varieties.

Crop-livestock systems

Most farmers produce both food crops as well as raise livestock, and for resource-poor farmers, getting the most out of this combination is very important. First, livestock can act as an extremely beneficial and cheap form of additional nutrient supply for fields – collecting, transporting, converting and depositing nutrients. When farmers tether their animals in fields overnight, the animals will deposit up to 95% of the nitrogen and phosphorus they consume during the day through their urine and faeces. By selectively rotating the tethering location, entire fields can gain, with the manure also helping to improve soil structure, biological activity and water-holding capacity. Long-term fertility trials on the savanna soils of West Africa show how beneficial animal manures can be (Figure 5.38).

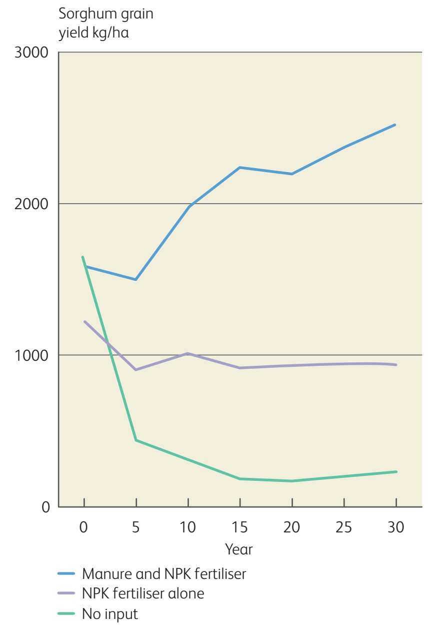


Figure 5.38 – The long term impact of the combination of fertilisers and manure on sorghum yields in Burkina Faso over 30 years[160]

In addition, farmers can further integrate animals and cropping productively by planting N-fixing, forage legumes, such as cowpea, intercropped with the crop plants. This improves soil quality and also the quality and quantity of animal feed. Careful ecological management of crop-livestock systems can create virtuous circles:

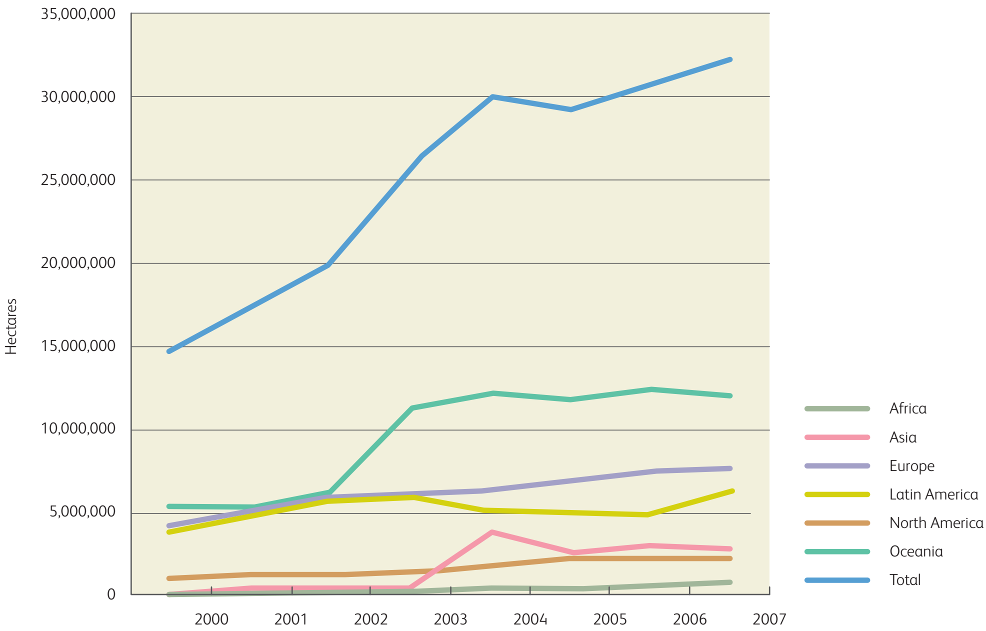
'*Cowpea thus feeds people and animals directly while also yielding more milk and meat, better soils through nitrogen fixation, high quality manure, which, used as fertiliser, further improves soil fertility and increases yields.*'[161]

Organic agriculture

Resource-poor farmers in developing countries have been practicing traditional forms of agriculture for centuries without reliance on synthetic fertilisers or pesticides. These traditional systems have much in common with the recently developed certified organic farming systems of the developed countries. Indeed, the FAO/WHO Codex Alimentarius guidelines define organic agriculture in a way that might apply equally as well to a modern certified organic farm in England as to a home garden in Indonesia that does not use synthetic inputs:

Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasises the use of management practices in preference to the use of off-farm inputs, taking

Figure 5.39 – Development of certified organic agriculture[165]



into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system.[162]

However, in the developed countries the certification of organic food production is considerably more stringent than the above definition. All synthetic fertilisers are banned and so are all herbicides and most insecticides and fungicides – the exceptions are various 'natural or simple' chemicals (in the UK the list includes sulphur, soft soap, copper and rotenone, some pyrethroids, iron orthophosphate and paraffin oil, and certain bacterial and other microorganisms).[163]

The amount of land under certified organic production has steadily grown over the past few decades. As of 2007, there were approximately 30.6 million hectares of certified organic farmland worldwide, representing about 1 % of total world production.[164] Figure 5.39 above shows how this practice has grown, largely in the developed countries.

However, official statistics do not include the millions of small producers who practice traditional non-certified organic agriculture. It is estimated that in developing countries, there are probably another 10 to 20 million hectares in this category.[166]

Certified organic farming in developed countries has a well established niche. Research supports the improvement of methods, and higher costs relative to conventional production systems are offset by the premium prices which organic products command. The question is whether an organic approach offers another route towards improvement of agriculture in developing countries. It certainly provides a profitable niche for the production of high value crops for export to the developed countries.

But is it a means whereby Africa and South Asia can transfer into highly productive yet sustainable agricultural production? In general yields from organic agriculture in the developed countries are lower than those using synthetic inputs, in part because the nitrogen levels are lower. However, a research group from the University of Michigan has recently challenged the view that more land is required to grow food entirely with biologically available nitrogen and without the use of synthetic fertilisers.[167]

In the UNEP/UNESCO 2008 report on '*Organic Agriculture and Food Security in Africa*' an analysis was made of the 114 cases in Africa previously studied by Jules Pretty et al.[168] It showed that there was a 116% increase in productivity by converting to organic or near-organic production (not necessarily certified). At the same time natural resources were building up, communities were strengthened and human capacity enhanced, thus improving food security by addressing many different causal factors simultaneously.[169]

Nevertheless, there are a large number of pros and cons to organic production which should be considered (Box 5.22).

Box 5.22 The pros and cons of organic farming

Pros:

- Minimal use of expensive agrochemical inputs;
- Reduced environmental impact;
- Increasing biodiversity leading to more resilient systems.

And for resource-poor smallholders, these are:

- The emphasis on the use of local resources;
- The low degree of mechanisation and high utilisation of local and family labour;
- The suitability for the cultivation of small areas;
- The ability to build on existing traditional skills.

Cons:

- Lack of readily available crop residues or manure to provide nitrogen and other nutrients;
- 'Knowledge-intensity' requiring a high level of capacity from farmers and research and extension systems to produce high yields.

And a number of environmental and social constraints:

- Higher labour requirements in labour constrained environments;
- Risks of failure associated with handling particularly difficult pests, disease or weather threats without outside inputs;
- Desire of farmers to use a range or combination of techniques;
- Perception of farmers that organic agriculture is a step backward, rather than forward;
- Lack of supportive government policies.

Whilst many of the principles of organic agriculture do have the potential to make positive impacts in improving soil fertility, pest management and agricultural production, more work is needed in the areas of research, extension and policy in order for this to become a productive approach on a wider scale. Moreover, extensive soil degradation and loss of nutrients, common in many parts of the developing world, necessitates a rapid increase in inputs of targeted, synthetic fertilisers both to increase yields and to produce greater amounts of green matter that will be available for incorporation as crop residues.

We would argue, at least in the medium term, for a hybrid approach to increasing agricultural production, rather than the promotion of either a solely ‘conventional’ or ‘organic’ system. Innovations in the smart use of inputs – under the general headings of integrated nutrient and pest management as described above – can be combined with holistic ecological techniques as discussed here. And, further, scientific breakthroughs in plant breeding, including biotechnologies, may provide crops with greater ability for nutrient uptake or pest and disease resistance, thus reducing the need for either synthetic or organic fertilisers or pesticides.

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Figure 5.40 – With the right inputs yields from rice crops in Bangladesh can be greatly improved

10. Conclusion

The devastating food price spike of 2008 drew attention to the underlying chronic hunger crisis. There are now probably more than a billion chronically hungry people in the world. In the 1960s and 70s the hunger crisis was resolved by a Green Revolution that greatly increased cereal production and averted famine in Asia and elsewhere. Today there is a need for a new Green Revolution – but one that is in many respects very different; production has to increase but in a way that is sustainable, environmentally friendly and equitable, ensuring that more food becomes available to the poor.

The priorities are:

- Increasing yields and the quality of the food that farmers grow, in particular ensuring that the basic staples contain the necessary vitamins and other micronutrients that people need to keep healthy;
- Improving the soil, ensuring that there is optimal provision of both nutrients and organic matter, and that plants can make maximum and sustainable use of what is available;
- Utilising water in an optimal manner, particularly given the greater incidence of drought in the future;
- Combating the major pests, diseases and weeds that are so devastating to developing country crops, in a way that minimises the use of harmful or counterproductive pesticides.

In each instance, choosing the appropriate technology mix will be important. Conventional technologies, for example inorganic fertilisers and pesticides, will remain a mainstay of the approach but they need to be used in ways that are much more selective and precise. Traditional and intermediate technologies have much to offer, and there will be increasing utilisation of some of the new platform technologies, including biotechnologies where they are superior in terms of their selectivity, environmental sensitivity and cost.

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