Science for Agricultural Development

Changing contexts, new opportunities

The Science Council of the Consultative Group on International Agricultural Research

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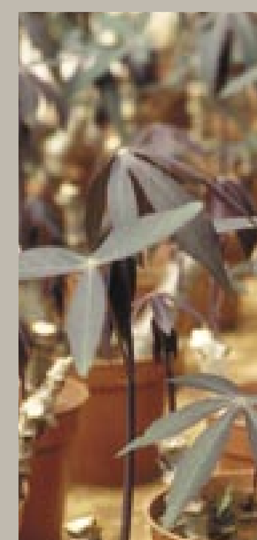

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Preface

I write at a time of tremendous global mobilization against poverty and food insecurity. Nowhere has this been shown better than at the recent United Nations World Summit in New York (14–16 September 2005), where all the world's governments reiterated their commitment to achieving the Millennium Development Goals (MDGs) by 2015 and pledged to contribute an additional US$ 50 billion a year of funding for poverty reduction by 2010. The Summit recognized that rural and agricultural development are an integral part of national and international development policies. Governments at the Summit reaffirmed the importance of a global partnership for development, as set out in the Millennium Declaration, and made direct commitments to increasing support for agricultural development. This year's G8 Summit at Gleneagles also put sustainable development in the spotlight. The G8 focused in particular on reducing poverty in Africa, where agricultural productivity improvements correlate closely with poverty reduction, as is discussed in this report.

Yet there is more to the story than simply making promises. We are standing at a convergence of international political will and emerging scientific breakthroughs, which provides an unprecedented opportunity for development and for global agricultural research to contribute to poverty reduction. There is little doubt that as 2015 approaches the challenges set out by the Millennium Declaration become more difficult to achieve, but increasingly science and technology are providing us with new ways of tackling these challenges using genomics, biotechnology, nanotechnology and bioinformatics. For example, researchers are working to improve the nutritional value of rice and to increase the level of vitamins and minerals in potato and cassava. Geneticists are starting to focus on crops that are essential to the livelihoods of millions of small-scale farmers, such as cowpea, pearl millet, sorghum, chickpea and groundnut. Bioinformatics, which uses computer algorithms to sort and analyse biological data, has already helped develop cereal varieties with greater tolerance to soil alkalinity and toxicity and which require less water.

We also have new ways of working, thanks to developments in information and communication technology. Through virtual networks and partnerships we can share information and knowledge at a speed and on a scale that is rising all the time. Increasingly advanced digital technologies provide us with the opportunity to share in a growing stock of knowledge accumulated through broader research partnerships. Popular technologies such as mobile phones are proving to be flexible tools that people can instantly use in their own language, tailoring them to their specific requirements. This is particularly important as it is the process of local adaptation that has always been an obstacle to the wide-scale acceptance of new agricultural technologies. Another way to address this issue is to make farmer participation and feedback an integral part of agricultural research methodology. There are other ways as well that new technologies are helping: 'e-agriculture' is starting to emerge, whereby agricultural information is presented in multimedia formats to improve knowledge sharing in local cultural contexts.

As readers will see, this report highlights the unique time that science for agricultural development has reached in its history – a time when many powerful new technologies are emerging from the developmental pipeline to improve our ability to work together and solve problems. The UN's global partnership for poverty reduction has set itself the challenge of halving world poverty in the next decade, and agricultural research has a clear role to play in that effort. The momentum, however, must be maintained and even intensified. Arctic explorers are only too aware of the reality of negative drift, whereby the overnight movement of ice sheets can erase the distance painstakingly gained during the previous day. In a similar way, the world's 'explorers' in agricultural development must continue apace, otherwise they will make little progress towards their goals. Without significant impetus in the short term the MDGs will become more difficult to reach as 2015 approaches.

This publication provides a timely snapshot of the state of science for agricultural development. It is the first in a proposed series of biennial reports that will provide fascinating reading as they keep track of the evolution of agricultural development and its role in achieving the MDGs.

Per Pinstrup-Andersen
Chair, CGIAR Science Council
November 2005

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Executive summary

Science has greatly increased the productivity of major food staples such as rice

Photo: FAO

Science for agricultural development has, over the past four decades, delivered real benefits to farmers, processors and consumers through the development and implementation of new knowledge and technologies. However, there remain more than 800 million undernourished people, mostly in developing countries, who will need significant increases in local production to reduce their food insecurity. It is in these areas that increases in agricultural production are needed most, and technologies that can improve disease resistance and drought tolerance and reduce pressure on natural resources are going to be essential for meeting this challenge. The Millennium Development Goals (MDGs) present steeper challenges today than have been faced in the past, in terms of both the focus on truly disadvantaged groups (such as the poor, women and children) and the timescale in which they are to be achieved (by 2015). This report contributes to efforts to meet that challenge by analysing and sharing knowledge about recent trends, current status and emerging issues related to the application of science to agricultural production.

The report is written with four main worldwide audiences in mind: decision makers in the development community, the public-sector research community, the private-sector research community and the community of development practitioners. If the report can help these groups to understand each others' approaches and aspirations a little better, it will have contributed to the 8^{th} MDG: *Develop a global partnership for development*.

The report recognizes that for research to have impact, many players in the afore-mentioned groups have to be involved. In research communities, scientists from disciplines far beyond agricultural science all have a major contribution to make. Natural and social scientists increasingly need to work in partnership, and they also need to communicate with national and regional policy makers, local communities and development experts working with bilateral and multilateral donors. All those involved in the research and development (R&D) chain from discovery to adoption need to learn lessons from past successes and failures by improving the way they measure the impacts of different research projects and programmes (Section 2).

The science of the 20^{th} century has enabled today's farmers to feed almost twice as many people from virtually the same area of land as was used 40 years ago; the science of the 21st century has much more to offer. Future increases in agricultural production can only hope to impact on poverty reduction in the long term if they contribute directly to improving both local and global natural resource management. This report highlights a number of the most innovative partnerships in science for agricultural development, including case studies that illustrate how bringing together farmers or fishers with researchers and communication specialists can help to transform scientific progress into lasting benefit for poor communities, which in turn translates into economic development for poor countries. Unique partnerships can also be found at the cutting edge of science: the publicly funded International Rice Genome Sequencing Project has helped to unravel the rice genome. Because of this project, scientists now have the opportunity to incorporate beneficial traits such as drought and disease tolerance into rice and other staple crops. Genomics research also forms the basis of recombinant vaccines, which offer advantages over conventional vaccines in terms of safety, specificity and stability. An example is given of research on East Coast Fever, a disease of cattle that threatens an estimated 25 million animals. Passing reference is made to emerging technologies (e.g. nanotechnology) that give a glimpse of exciting new scientific opportunities for the future (Section 3).

The potential benefits that these advances can bring, however, have to be understood in the context of a changing global environment. Although the rate of population growth is slowing at a global level, variable weather patterns caused by climate change will make it more difficult to increase food production in many parts of sub-Saharan Africa, South Asia and Latin America. It should not be forgotten, though, that sustainable land use for agriculture and forestry can contribute to global efforts to reduce human impact on the climate system. To this end, research is needed to develop crop and livestock systems that can adapt to changing local environments. Such systems have also to take into account the consequences of globalization, related to trade and changing consumer preferences (Section 4).

Crucially, it requires funding to take advantage of these scientific opportunities for agricultural development. Section 5 analyses trends in science funding from 1981 to 2000. Over the past 5 years, worldwide investment in science has risen by a third to reach 1.7% of the world's Gross Domestic Product (GDP). However, there are marked regional variations: spending on science is falling in sub-Saharan Africa and rising most notably in the Asia and Pacific region. For agricultural research and development (R&D) specifically there is a disparity between rich and poor nations that reflects marked differences in investment levels. And within regions, relatively few countries account for the majority of investments. For example, in 2000 France, Germany, Japan and the United States undertook two-thirds of the public research among rich countries, while Brazil, China, India, South Africa and Thailand undertook more than half of all developing-country public agricultural research. Furthermore, the majority of developing countries are spending less on agricultural R&D, both as a proportion of all developing countries and in relation to the rest of the world. Section 5 also draws attention to some of the partnerships, formed in response to funding challenges, that are led by developing countries.

The report ends with a chapter that highlights conclusions and then outlines specific messages for each of the four intended audiences in turn. It concludes that agricultural R&D has done a lot in recent decades to help feed the world. It has not been a cheap process, but it is clear that the benefits greatly outweigh the costs. However, to keep the process going, governments must invest more – not just in terms of amount, but also over longer periods and on the most promising areas in terms of socio-economic impact. And it is vital that ongoing scientific processes take into consideration not only the immediate need to raise production, but also the wider picture; we must consider the needs of those people who do not yet have food security, and ensure that we care for the environment that we all share. These take-home messages are found in Section 6, which starts on p. 43.

Section 1 Introduction

It is a cliché to say "we live in a rapidly changing world" or "the world is like a global village", but that does not stop such sayings from being true – at least in part. Yet for millions of people around the world, these phrases refer to changes that have brought few benefits to them, to the extent that they have found the global village to be an uncaring community; one that continues to let a billion people live on less than one dollar a day, and where 800 million people are not getting enough food (UN Stats 2005). However, there is hope that global village neighbours may yet become friends. The build-up to the G8 Summit held in Scotland, July 2005, saw millions of ordinary people around the world attending the Live8 pop concerts to show support for the 'Make poverty history' campaign. But while there is a question as to the long-term benefits from such headline-grabbing events, there is no doubt that scientific research has a lasting impact.

Grains form the basis of many rural diets
Photo: Crop Post-Harvest Programme (DFID)

Aim of this report

This document has been compiled in order to analyse and share knowledge relevant to the application of science and technology to agricultural production. The hope is that by so doing we will help shape global perspectives and priorities with regard to agricultural science and therefore maximize its contribution towards meeting the Millennium Development Goals (MDGs).

Specifically this report will draw out messages that relate to four main communities:

- the development community, consisting of people who make decisions relating to investments in R&D to boost agriculture in developing countries. This includes the staff of inter-governmental agencies such as the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO)
- the public-sector research community worldwide
- the private-sector research community worldwide
- the international community of development practitioners.

Each of these communities makes its own contribution to ensuring that the outcomes of research for agricultural development help to reduce poverty and hunger – the subject of the first of the MDGs.

Millennium Development Goals

There are eight MDGs (listed at http://www.un.org/millenniumgoals) that all 191 United Nations Member States have pledged to meet by 2015. The first Goal: *Eradicate extreme poverty and hunger* – is the one directly targeted by agricultural development. However, all the goals are to some extent interlinked. Producing more and better quality food can lead to improvements in nutritional status and therefore indirectly contribute to Goals 2: *Achieve universal primary education* and 4: *Reduce child mortality*, as better-fed children are more receptive to learning and more resistant to disease. Research on agriculture will necessarily overlap with environmental and water concerns, and can thus contribute to Goal 7: *Ensure environmental sustainability*. And farming is one of the areas where the international community is starting to realize that women's contributions are vital, so including everyone in agricultural research works towards Goal 3: *Promote gender equality and empower women*.

Each of these MDGs has measurable targets. For Goal 1 these are to:

- reduce by half the proportion of people living on less than a dollar a day, and
- reduce by half the proportion of people who suffer from hunger.

These targets are measured against benchmark data for 1990. Table 1.1 shows the progress made in the 11 years since the data were assembled. Many parts of Asia have significantly improved, but there is a lack of progress elsewhere.

How a global partnership can help

The 8th MDG is to *Develop a global partnership for development*. It is true that to a certain extent this has been done before: in 1945 the global partnership that is the United Nations (UN) was created, as was its specialized agency, the Food and Agriculture Organization (FAO). However, the uniting focus of the world community at that time was on economic development in the aftermath of the Second World War. Individual countries maintained (or strengthened) aid programmes to developing countries, and agriculture was a major focus. For example, the United States Agency for International Development (USAID) increased its funding sharply from a low in 1952 (of US$ 2 million) to a peak of almost US$ 250 million (both at 2000 prices) in 1986 (although the amount has since declined). At that time, all countries faced the same drive to increase agricultural production, and governments in developed countries invested heavily in agricultural research. This investment paid off, as pointed out by Blaxter and Robertson (1995): "During the 50-year period from 1936

Representatives from 40 nations met in Quebec in 1945 and formed the FAO

Photo: FAO

Table 1.1 Progress towards the first Millennium Development Goal

	Population <US$ 1 PPP per day (%)		Population undernourished (%)	
	1990	2001	1990–1992	1999–2001
Northern Africa	2.6	1.9	5	4
Sub-Saharan Africa (SSA)	46.9	46.4	35	33
Latin America and Caribbean (LAC)	10.9	10.0	13	10
Eastern Asia	33.0	16.6	16	11
Southern Asia	39.7	30.4	25	22
Southeast Asia	18.4	10.2	17	13
Western Asia	1.6	3.7	7	10
Commonwealth of Independent States	0.5	5.0	Asia: 18 Europe: 4	Asia: 27 Europe: 4

Source: Report of the UN Secretary-General on Implementation of the UN Millennium Declaration (August 2004).

Notes: High-income economies, as defined by the World Bank, are excluded.
PPP = purchasing power parity.

to 1986 the modern agricultural revolution occurred in which, for the first time, science was properly harnessed to the improvement of agricultural productivity."

What makes the new global partnership of the 21st century unique is that is has identified a reduction in extreme poverty and hunger as its priority, and the research community is confident it can make a significant contribution. In Africa, for example, estimates have shown that a 10% increase in agricultural productivity is associated with a 7.2% decrease in poverty, while in India a similar increase has a 4% decrease in poverty in the short term and a 12% decrease in the longer term (IFPRI 2004).

Structure of the report

If the world is a global village, then it is a very large and complex one, where everyone has increasing accessibility to information and potential partners. It is fair to say that a report of this length could never analyse all the available relevant information. Instead it uses case studies to illustrate what has been achieved so far and to identify opportunities for even more to be achieved in the future.

The report starts by providing examples of past research and the impact it has had on development. Particular attention is drawn to some of the factors that have affected the time taken for research to feed through into application (Section 2). Section 3 highlights recent successes that have come about following advances in biotechnology and partnership approaches, and offers glimpses of future potential. Section 4 touches on the possible impact of globalization and climate change on research needs, while Section 5 presents new data on recent trends (1981–2000) in global investment in agricultural R&D, and considers recent changes to the national agricultural research systems of developing countries. Finally, Section 6 draws out some of the significant messages for different readers of this report, tailoring them to the broad interests of the four communities referred to earlier.

Section 2 Understanding the continuum from research to developmental impact

This report is mainly about research, but for research to contribute to meeting the MDGs, many players other than agricultural scientists have to be involved. Many scientific disciplines outside of the biological sciences can contribute to enhancing food production: for the past two decades, the social sciences have played an increasingly important role. Social sciences not only affect economics and the interaction between researchers and food practitioners, but they also have a role in the institutional context, the legal infrastructure and the policy arena. Hence the title of this report is *Science for Agricultural Development* and not *Agricultural Science for Development*.

Delivery of impact, however, goes far beyond delivery of research outcomes. It involves the whole global community of development experts and policy makers, both in developed and developing countries. Effective communication between these groups is vital if the MDGs are to be met. The continuum between research and developmental impact is a critical part of that process.

Measuring returns to investment in R&D

Science for agricultural development has a good track-record of delivering real benefits to poor farmers and consumers through new crop, livestock, fish, forest and farming technologies that improve both productivity and farmers' incomes, thereby contributing to poverty reduction (Evenson and Gollin 2003; Raitzer 2003; Johnson 2005). Such technologies are also helping to protect the environment by enabling land and other natural resources to be used more prudently (box 2.1).

These and other studies provide overwhelming evidence that science-based sustainable agriculture can allow millions of farmers to escape poverty, which is essential if the MDGs are to be achieved. Despite this promise, it is unfortunate that the returns to investment in science for agricultural development have for the most part been measured in an *ad hoc* and random manner, with standards and approaches differing significantly among studies.

In 2002, the Science Council of the Consultative Group on International Agricultural Research (CGIAR) commissioned an independent study to compare the benefits gained from its research against the total cost of operating the whole CGIAR system up to 2001 (Raitzer 2003). The analysis, delivered to the CGIAR Science Council in 2003, found that the value of documented benefits generated surpassed the total investment in the system, even under the most restrictive set of assumptions. Raitzer produced five benefit–cost ratios, each showing results obtained using different assumptions for the important measures of benefit. The most conservative assessment yielded a benefit–cost ratio of 1.9:1. In other words, the CGIAR has generated an indisputable (and respectable) return of nearly two dollars for every dollar invested. The most generous scenario yielded a benefit–cost ratio of 17.2:1.

Box 2.1 Significant successes from investment in science for agricultural development

- New rice for Africa – NERICA – which combines the ruggedness of African *Oryza glaberrima* with the high productivity of Asian *Oryza sativa*. NERICAs are now planted on over 100,000 ha across Africa and are helping poor countries reduce rice import costs as well as increase incomes of their poor farmers (CGIAR 2005a)
- In Uganda, development and dissemination of cassava varieties resistant to cassava mosaic virus (CMV) has resulted in an average yield increase of 10 tonnes per ha, with estimated benefits of US$ 140 million compared with an investment of US$ 5 million (Lenné 2000)
- Improved aquaculture techniques, including new strains of tilapia fish that grow 60% faster and yield three harvests per year, are boosting household incomes and nutrition in many countries (Johnson 2005)
- Export vegetable production in Kenya, the country's fastest growing agricultural sub-sector accounting for almost 13% of GDP in 2003, is providing benefits for 50,000 small-scale farmers and hundreds of thousands of semi-skilled and unskilled Kenyans, predominantly young females with children who would struggle to find alternative employment (Lenné et al. 2005)
- Without the productivity increases achieved since 1960, an additional 350 million ha of land – an area about the size of India – would have to be cropped to feed the world's population. Such an expansion would have moved farming onto highly erosion-prone soils and destroyed forests and other natural vegetation together with the biodiversity they support (CGIAR 2004).

Looking forwards, this means that the total investment in the CGIAR from 1960 to 2001 of US$ 7 billion will result in US$ 123 billion of benefits by 2011 (all calculated in terms of 1990 US dollars). Yet even this highly favourable result probably understates the total return on investment. For example, it does not include the following:

- Benefits from the CGIAR's many research areas that are inadequately documented and/or inherently difficult to value, such as impacts on policy and natural resource management
- The multiplier effect, by which every dollar of farm income contributes an additional US$ 0.5–1.0 to the local non-farm economy through higher demand for other products and services
- Land savings and their invaluable contribution to protecting biodiversity and watersheds, gained from the intensified cropping of existing farmland.

The bottom line remains that investment in the CGIAR has paid off handsomely, even when analysed from the most conservative perspective. The Raitzer study's other main but related conclusion is that the CGIAR can and should do more to document how it affects the welfare of poor farmers and consumers in the developing world.

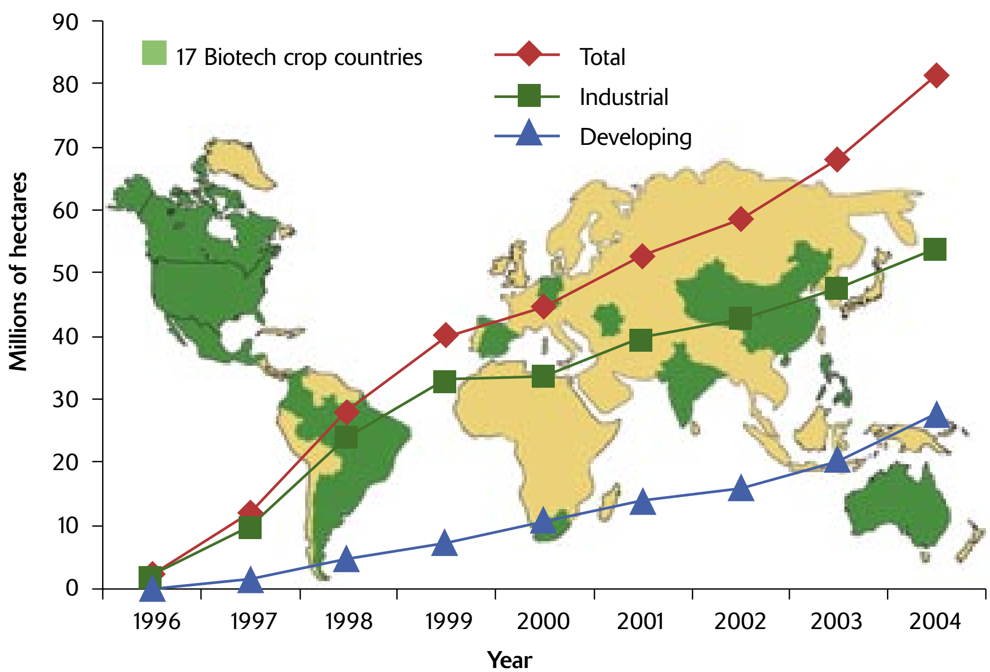
The private sector and society's role

Improved studies on impact will help us know what to expect from future advances in science, but lessons also need to be learned from the response of society to some earlier advances. For a start, advances in information and communication technology mean that people as a whole are now better informed. They are also more likely to express their views on acceptable practices, for example in relation to animal welfare or environmental issues.

The first transgenic crops – which were genetically modified using recombinant DNA techniques – were planted exactly a decade ago (James 2004). During the period 1996–2004, the total global area devoted to growing transgenic crops increased more than 47-fold, from 1.7 million ha in 1996 to 81 million ha in 2004, with an increasing proportion grown by developing countries. This is one of the fastest rates of crop technology adoption in modern agriculture, and it has occurred despite severe limitations on the planting of transgenic crops in Europe, where public opinion has played a role in blocking adoption. It is estimated that, in 2004, transgenic crops were grown by 8.25 million farmers in 17 countries (figure 2.1), an increase of 20% (13.3 million ha or 32.9 million acres) over 2003. More than a third (34%, i.e. 27.6 million ha) of the global transgenic crop area in 2004 was in developing countries, notably in Argentina (16.2 million ha), Brazil (5.0 million ha) and China (3.7 million ha), with increasing amounts being grown in India, Mexico, Paraguay, the Philippines, South Africa and Uruguay. By 2010, it is expected that 15 million farmers will be cultivating 150 million ha of transgenic crops globally.

The Green Revolution was driven by two crops – rice and wheat. Today, the adoption of transgenic crops is based on four species – soybean, maize, cotton and canola – and two biotechnologies – herbicide tolerance and insect resistance. The main transgenic crops currently grown by farmers are herbicide-tolerant soybean and insect-resistant, herbicide-tolerant maize, cotton and canola (James

Figure 2.1 The global distribution of transgenic crops in 2004 and growth in their coverage since 1996 (million ha). ***Source: James (2004)***



2004). These four herbicide-tolerant crops together account for 72% of the global transgenic crop area, and they have been developed almost exclusively by the private sector.

Higher yielding crops and the inputs required to support them can bring enormous benefits to the poor through reduced risks, enhanced efficiency, higher incomes and lower food prices. By raising productivity, improving living standards and creating sustainable economic growth, the Green Revolution has reduced the vulnerability of the poor and lifted millions of people out of poverty (Evenson and Gollin 2003). There is great potential for new and safe agricultural biotechnologies to underpin further productivity increases and decrease the risks to food security faced by poor communities (FAO 2004). This will help meet the immense challenge of feeding an additional 2 billion people over the next 30 years without further depleting the natural resource base or harming the environment. Responsible partnerships between the public and private sector have the potential to speed up the journey from research to impact in this area.

The time-line from research to impact

A research lag is the time between starting to investigate new technology, and arriving at one or more finished options. Basic and strategic research generally have longer research lags than more applied or adaptive research. The length of the lag also depends on the nature of the research, the agro-ecological environment, the target commodities, and the degree of involvement of the stakeholders – especially the end-users – in the research process. For example, applied or adaptive research such as crop management research may require only 3–4 years before new options emerge, whereas conventional plant breeding on annuals usually requires at least 8 years, rising to more than 15 years for perennial crops. Ruminant livestock usually require even longer lags, caused partly by their longer breeding cycles.

New cultivars must be certified and multiplied before reaching farmers' fields
Photo: FAO/17737/A.Conti

After the research has matured into new options there is the inevitable development lag before farmers can begin to adopt the technologies. For example, an improved crop will need seed certification and multiplication of cultivars, which may take a further 3–4 years. Experience has shown that involving farmers earlier in research and adoption processes can substantially reduce this development lag. Even then it may take another 20–30 years before adoption reaches its ceiling, determined by agro-ecological conditions, the infrastructure for marketing inputs and outputs and the characteristics of the technology. This period of time is referred to as the adoption lag.

After the adoption ceiling is reached it is usually only a matter of time before the new technology becomes old and starts to depreciate and/or become obsolete, leading to farmers rejecting it. Depreciation depends on the nature of the technology, for example disease or insect resistance can decline as new strains evolve. It can be delayed or slowed down by undertaking maintenance research. Obsolescence, in contrast, is largely affected by the rate at which new technology options are developed. Generally, the more investment in new rounds of research, the shorter the time to rejection of existing technology options and the faster the rate of adoption of new and better ones. As users increasingly adopt the new technologies, their income streams should improve, providing the basis for improvement in the welfare of the poor and hungry.

The greater participation of farmers and other stakeholders in the development, adaptation and application of new technologies is speeding up adoption. The involvement of local people is also a key element in the successful adaptation and application of innovations developed in one place to other countries and regions, often referred to as research 'spillovers'.

Agro-ecologies and research spillovers

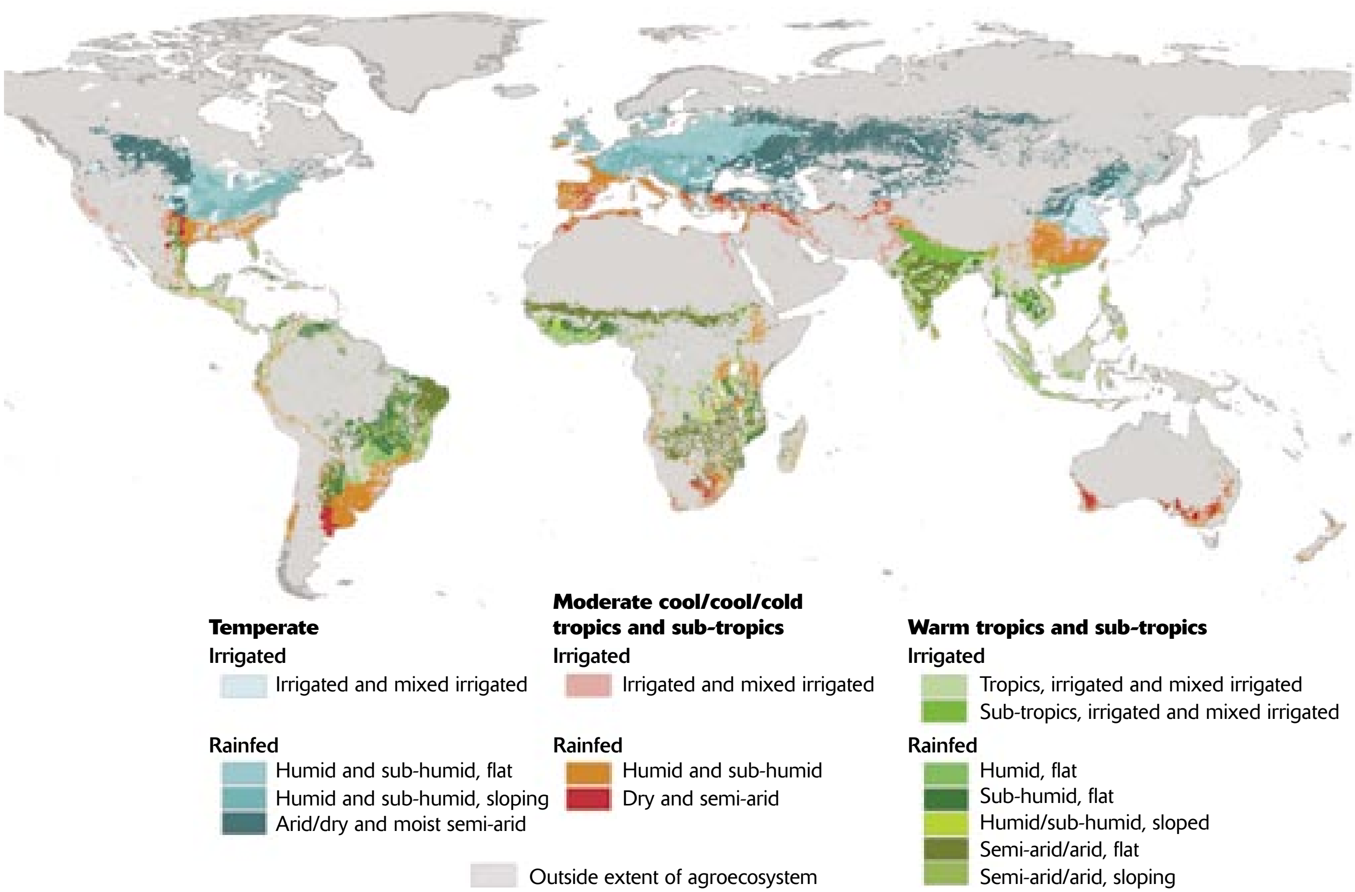
Science and technology spillovers have been a pervasive feature of the history of agricultural development. Alston (2002) contends that up to half the local productivity gains in agriculture over the past few decades can be attributed to 'spill-in' technologies developed elsewhere. For example, Pardey et al. (1996) showed that research conducted on wheat by the International Maize and Wheat Improvement Center (CIMMYT) and on rice by the International Rice Research Institute (IRRI) – almost entirely in developing countries – provided huge economic benefits to the United States (US). This was owing to technology spillover, whereby wheat and rice varieties generated for developing countries were either adopted directly by US farmers or, more often, incorporated into US-focused crop improvement programmes (see also Evenson and Gollin 2003). It must be recognized that agricultural technologies – and even the underlying knowledge and research techniques – move across borders, both by design and by accident.

Many agricultural technologies are, however, sensitive to local climate, soil and other biophysical attributes, making them less easily transferable than technologies from the medical or information sciences sectors. For example, soybeans are sensitive to the length of the day, so different varieties must be developed for different latitudes. Likewise, many tropical soils are naturally acidic while temperate soils are not. Consequently, crops that thrive in temperate soils can falter or fail under tropical conditions. Variability in agro-ecological conditions means that imported technologies often have to be adapted to local conditions before they can be used (as was usually the case with Green Revolution wheat and rice varieties). Nevertheless, for some developing countries and for some types of technologies, the least-cost option has been to import and adapt technology, and will continue to be so.

However, while the importance of technology spillover is well recognized, it has often proved difficult to incorporate this into research planning. In part, this is because there is limited (informed) use of data on the distribution of the biophysical attributes of the world's agricultural production environments. Figure 2.2 shows an agro-ecological typology of the world's cultivated systems. This type of map goes beyond showing only the rainfall and temperature attributes that underpinned, for example, the FAO's agro-climatic characterization (1978–1981) and the agro-ecological efforts of the CGIAR (TAC/CGIAR 1991). It makes the important distinctions between irrigated and rainfed lands and sloping and flat lands. Furthermore, the map focuses attention on the actual rather than the potential area of cultivation. These features bring greater geographic specificity to the search for homologous production conditions – either as a potential source for improved knowledge or technology, or as a potential new recipient area for ideas and technologies developed elsewhere.

The regional distribution of agro-ecological attributes is presented in table 2.1, which, despite the highly aggregated data it contains, suggests that there is still scope for technology spillovers. For example, moderately cool tropical and sub-tropical areas account for around 14.5% of the cultivated area in sub-Saharan Africa and also make up a significant share of the cultivated lands of

Figure 2.2 Distribution of the world's cultivated systems by agro-ecological class



Data source: Wood et al. 2000. *IFPRI 2005*

Table 2.1 Agro-ecological attributes of the world's cultivated systems

Share of agricultural area	Temperate: Irrigated and mixed irrigated	Temperate: Rainfed	Tropics and subtropics: Moderate cool	Tropics and subtropics: Warm, irrigated and mixed irrigated	Tropics and subtropics: Warm, sloped rainfed	Tropics and subtropics: Warm, flat rainfed	All agro-ecologies
	(percentages)						
Latin America and Caribbean (LAC)	0	0	31.0	3.2	16.5	49.4	100
Brazil	0	0	15.0	1.2	18.1	65.8	100
Asia and Pacific	7.7	14.9	26.4	20.6	11.5	18.9	100
China	18.6	35.3	38.3	1.1	1.8	4.9	100
India	0	0	5.0	47.8	8.6	38.6	100
North Africa / Middle East	4.5	16.8	78.7	0	0	0	100
Sub-Saharan Africa (SSA)	0	0	14.5	1.2	21.4	62.9	100
Eastern Europe	8.2	90.5	1.2	0	0	0	100
Developed countries[a]	4.9	63.1	29.3	0.5	0.9	1.3	100
Japan	26.8	59.7	13.5	0	0	0	100
US	5.5	66.4	22.7	0.7	1.6	3.0	100
World	4.5	33.1	23.8	6.3	9.2	23.1	100

Source: Pardey et al. (2005), based on the data and digitized maps underlying Wood et al. (2000).

Note: Cultivated systems are defined as those areas of the world where cropland exceeds at least 30% of land area, as detected by satellite interpretation.

[a] Includes Organisation for Economic Cooperation and Development (OECD) countries (but excludes Mexico).

Brazil, China and the US. Similarly, the warm tropical and subtropical, flat rainfed areas that form the greater part of sub-Saharan Africa also represent a significant proportion of the cultivated land in Brazil and India. There is potential to incorporate increasingly specific screening criteria, such as soil characteristics, climate variability, and the like, in order to gain ever more specific matches.

However, both the supply of and the demand for spillover technologies are changing. Rich countries in particular are moving away from the type of agricultural R&D that is most easily adapted and adopted by developing countries (Pardey, Alston and Piggott in press). In addition, intellectual property rights and other regulatory policies, including biosafety protocols, trading regimes and specific restrictions on the movement of genetic material, are increasingly influencing the extent to which such spillovers are feasible or economically viable.

On the demand side, some developing countries (such as Brazil, China and India) have expanded their basic research capacity, reducing their dependence on adaptive R&D. These countries have in turn become a potential source of new technologies for the poorest and smallest countries, which will (and often should, given economic realities) continue to rely on adaptive research on technology from other countries. Some examples of past, present and future advances that can contribute to this technology pipeline are described in Section 5.

Section 3 Scientific opportunities: potential for success

The miracle of the past four decades is that today's farmers are feeding almost twice as many people with better quality food from virtually the same land base (Pardey and Beintema 2001). By increasing yields on the land that is best suited to agriculture, today's farmers have been able to leave vast areas untouched and therefore saved forests and biodiversity. However, it is vital that we continue investing in and advancing scientific opportunities so that we not only maintain a favourable food balance and protect natural resources but also speed our progress towards achieving the MDGs.

The potential of systems approaches

From humble beginnings and through 15 years of evolution, participatory approaches are now part of the mainstream in science for agricultural development. Along the way this has led to the use of 'innovation systems' approaches, where relevant stakeholders use certain techniques and procedures to create knowledge for use and diffusion (Hall et al. 2004). Participation is inherent to the innovation systems approach.

This concept is still evolving. Spielman (2005), for example, suggests the need for more analysis of the agents involved and their behaviour, the institutions that condition that behaviour, and the diverse interactions that characterize it. Furthermore, he points out that such studies should include more in-depth investigations of policy options that may affect the innovative process and its welfare-improving outcomes. He is not alone; it is now widely recognized that the constraints faced by many agricultural research organizations and systems around the world are institutional in nature (Byerlee and Alex 1998). Consequently, there is a strong movement to link agricultural research efforts with the social, economic and policy domains in which they operate and hope to effect change. In other words, science for agricultural development is becoming more inclusive, consultative and participatory. Such improvements reveal more opportunities for progress but also new challenges. One such challenge is the need for science in agricultural development to be responsive to and engage with a widening range of interest groups, agendas, priorities and opportunities.

The idea is that research should be more flexible and inclusive – and increasingly it is becoming so. Science for agricultural development now focuses more on partnerships, multiple knowledge bases, innovation triggers and champions, reworking the existing stock of knowledge, institutional learning and capacity development, and social responsibility. Donors and research organizations are beginning to direct more support to building the capacity of local systems to generate, use and share new technology, recognizing that this is the route to greater impact from research investments.

The continuum from research through to impact is a complex system in which the interactions of many people and organizations continuously throw up possibilities and challenges for new players to address with fresh advances. This process is driven by technology development and user demand, which results in technological change (Douthwaite 2002). Conversely, the development of this continuum is driven by feedback loops and learning processes that enable those involved to respond to emerging needs and circumstances that cannot be predicted. Such a systems perspective on agricultural innovation offers the potential of realizing the promise of science and technology in the context of socio-economic development and merits increased investment in future.

Managing diseases and pests in Andean potato systems

Potato is a major crop in the Andes across Bolivia, Colombia, Ecuador and Peru. It is the basis of the livelihood of millions of farmers in these countries. Research by the International Potato Center (CIP) over the past 30 years has led to the development of late blight-resistant varieties of potato in Peru as well as integrated pest management (IPM) strategies for Andean potato weevil in Peru, Bolivia and Ecuador. A systems approach involving farmers, researchers and communication specialists is promoting the dissemination and adoption of improved potato protection technologies – both input-based and knowledge-intensive – with demonstrable benefits to all (Fonseca et al. 1996; Ortiz et al. 1996; 2004; Godland et al. 2004; Zuger 2004; box 3.1).

Potatoes, mainstay of Andean agriculture

Photo: FAO

The 'resistance movement' for potato in the Andes demonstrates how inclusive, consultative and participatory relationships can be successfully developed. Farmers were shown how to access new sources of information and were given the freedom not only to learn by discovery but also to apply their creativity to managing new opportunities provided by research. This experience enabled them to take better decisions on potato management in general. And it was a two-way road: researchers also learnt more about farmers' criteria for selecting desirable potato phenotypes and adopting different options in the weevil IPM package (Godland et al. 2004; Ortiz et al. 2004). The process was driven by feedback and mutual learning that enabled both groups to respond to changing needs and circumstances. Facilitated by communication specialists, this innovation system is realizing the promise of science for agricultural development for the benefit of small-scale Andean potato farmers.

Managing an inland fisheries system in Bangladesh

Another of the CGIAR centres, The WorldFish Center, is working to improve fisheries management and the livelihoods of poor fisherfolk in Bangladesh. In partnership with the national Department of Fisheries (DoF), the Government of Bangladesh, 11 NGOs and Bangladeshi fisherfolk, the Center is developing alternative models for fisheries management through learning, testing and piloting partnership approaches that bring together all stakeholders at all levels (box 3.2). These

Box 3.1 Resistance movement

Twenty-first century Peru is a world away from 19th century Ireland, but their farmers share a common curse: potato blight. This fungal disease, caused by *Phytophthora infestans*, swept through rural Ireland in the mid-1800s, killing thousands through famine and forcing many more to emigrate. Today, blight's impact on farmers in the Andes – its original home – is less dramatic but nonetheless distressing; potato blight ruins around 15% of this major crop, a high price to pay for poor farmers scraping by on less than a hectare of land. But unlike their Irish forerunners, Andean farmers are not simply victims of the disease; they have new methods and technologies to fight the blight.

To win this struggle, Peru's farmers have gone back to school – in their own fields. Farmer field schools were pioneered in Asia in the 1980s to help rice growers learn such new agricultural techniques as integrated pest management (IPM) and how to use improved seeds and other technological advances. More than this, field schools capitalize on farmers' existing knowledge and judgement, teaching them problem-solving skills so that they can deal with their own challenges more effectively and encouraging them to teach others around them.

In the late 1990s, the International Potato Center (CIP) in Lima, and CARE, a non-government organization (NGO), introduced farmer field schools in the Peruvian Andes to help farmers deal with blight and another serious invader, the Andean potato weevil. Although farmers were painfully aware of the effects of both pests, and had spent what little money they had blasting their crops with pesticides, they knew little about what caused the outbreaks, how environmental conditions hastened their spread, which pesticides were most effective and other ways of controlling disease.

The field schools set about changing that, and the results are encouraging. Participants not only know more, but they have put their learning into practice, applying pesticides more effectively, adopting alternative pest management strategies (for instance, using *Beauveria*, a native fungus that attacks weevils) and better protecting their harvests. The result is less damage to their crops and, in some cases, higher yields as well. This translates into an average increase in farmers' income of US$ 236 per ha per year, in the case of blight, and US$ 154 per hectare per year in that of weevils.

By actively participating in the schools, farmers can teach a lot to the experts about what works in the world beyond the laboratory. *Beauvaria*, for example, which farmers mix into the soil at storage sites, works well in those parts of the Andes where farmers keep their potatoes in the ground but not in others where different storage methods are used. In the case of blight, new genetically resistant potatoes developed by CIP are the most powerful advance against the disease. By introducing these new cultivars through field schools, researchers were able to collect more data about which ones maintain their resistance and quality in real-life growing conditions, in large part by watching and listening to the farmers themselves. As Peru's potato schools clearly show, technologies do best where their creators understand the consumers, and *vice versa*.

approaches have enabled poor fisherfolk access open waters by helping them organize various groups, each focused on specific water bodies. The NGOs and DoF have provided training and resources (Muir 2003; WorldFish Center 2005).

Through the Bangladesh Community-based Fisheries Management project, a basket of alternative management options is enabling poor fisherfolk to both improve their livelihoods and contribute to sustainable management of the waters. This effort brings together different scientific and social

Box 3.2 Net benefits

"Give a man a fish and you feed him for a day; teach a man to fish and you feed him for a lifetime," so the Chinese proverb goes. Today, such ancient advice is no longer enough to keep poverty at bay. At least 23 million people in fishing communities in the developing world live on less than one dollar a day. Bangladesh is a case in point. Fishing accounts for 3.5% of the country's gross domestic product (GDP) and employs around 1.5 million full-time professional fisherfolk and 11 million part-time, mainly subsistence fisherfolk who depend on the country's abundant inland fisheries. Altogether, these fisherfolk and their families represent about 50% of Bangladesh's population. For many Bangladeshis, fish mean more than just money: they supply 80% of the animal protein in the average Bangladeshi diet. For subsistence fishers and their families, their daily catch is often their only source of protein and essential minerals.

But times are tough for Bangladeshi fishing communities. Many of their problems are man-made, among them declining fish stocks, environmental degradation, poor access to markets, fluctuating prices and fierce competition from commercial fishing operations. In recent years, there have been clashes between fisherfolk and the government over fishing rights and access to waters. Many more challenges come from nature itself; although Bangladesh was spared the great tsunami of December 2004, which devastated so many fishing communities across Asia, a steady stream of cyclones and floods keeps its fishing villages on the edge.

But in Bangladesh, the do-it-yourself spirit of the ancient Chinese proverb is evident in new ways of helping poor fishing communities to help themselves. An innovative partnership between the WorldFish Center in Malaysia, the Government of Bangladesh, nearly a dozen NGOs and, most critically, the fisherfolk and their families, has started to give fishing communities a greater say in how their waters are used and maintained. The initiative has established so-called 'community-based fisheries management' in 124 inland bodies of water. So far 25,000 fishing families have benefited from the projects, which provide training in good fishing practice, stock management and conservation as well as other income-generating activities.

Taking home the day's catch: Tangail, Bangladesh
Photo: K.Robinson/Panos Pictures

So far the results are promising. The fish are thriving: species diversity has increased by 14% and fish production has grown by 41% in the waters under community management. Relations between fisherfolk and the Government have also improved. With more say and more secure access to their traditional fishing grounds, fisherfolk feel less threatened and more protective of the inland waters. Government officials have also learned from their chance to work with – rather than fight against – fishing communities in the projects. Politicians now have a better idea of the challenges faced by poor fishing families and are adapting at least some of their policies, such as including a new exemption from tax on lease values, to help them. The partnership is now pushing for income tax exemption for fisherfolk, and is helping the DoF to draft new laws to protect fish sanctuaries. The challenge now is to show that such community-based management can boost fisherfolk's real incomes. If so, scaling-up will be the next challenge for the projects to tackle.

disciplines with policy makers, and the result is innovation, knowledge flows and feedback. It is likely to bring lasting improvements to Bangladeshi fishing communities and economic development to the region.

The potential of genomics

The huge scientific advances that have been made in genomics in the 20th and 21st centuries are already improving the productivity of crops, livestock, fisheries and forests (Gale 2003). Genomics provides information on the identity, function, location and impact of genes involved in the manifestation of economically important traits such as disease and pest resistance and tolerance to drought or acid soils (FAO 2004). Scientists can now produce genetic maps such as that of the rice genome (see box 3.3) that pinpoint the precise location and sequences of genes. Anchored in the unexpected discovery of synteny, whereby genome organization is to a certain extent conserved between species, comparative genomics helps us understand the genomic relationships between important crop plants, especially in the cereal family. Knowledge of biochemistry, physiology and genetics can now be pooled and used widely across all the cereal crops, including so-called 'orphan crops' such as sorghum and pearl millet, that have no immediate relatives but are nonetheless vitally important food crops for the poor in Asia and Africa.

Unravelling the rice genome

Rice is cultivated in more than 100 countries globally and is the staple food for about half the world's population. Current consumption trends suggest that about 4.6 billion people will be reliant on rice by 2025. To meet this demand, rice yields must increase by 30% over the next 20 years. Research to unravel the rice genome promises more rapid and spectacular returns than conventional breeding approaches (International Rice Genome Sequencing Project 2005; box 3.3).

Many research groups – in both developed and developing countries – are benefiting from the sequencing of the rice genome in their hunt for useful genes. Being a publicly funded project, the rice genome has fostered important public-sector partnerships and, in the delivery of the sequenced genome, generated international public goods. This research has also provided methodologies such as the sequence-assisted breeding method based on single nucleotide polymorphisms (SNPs) – where only one base unit is altered at a time – which are used to shorten breeding cycles and aid in the selection of desired traits in rice seedlings. Such methodologies can be widely applied in future rice breeding programmes. The sequence information is also being used to genetically engineer rice and incorporate beneficial biological and physiological traits such as resistance to drought.

Rice can be improved using new genetic technologies
Photo: FAO/19483/G.Bizzarri

Box 3.3 Grain gain

To appreciate the power of rice, take a walk along the Dragon's Backbone. This amazing system of rice terraces ripples up, down and across more than 60 square kilometres of Guangxi province in southeast China. In summer, when its millions of rice plants are in full flower, the Dragon's Backbone (or Longji, as it is known in Chinese) looks as if a giant chloroplast has burst open, spilling green discs down its hills and valleys. The sheer scale and complexity of Longji make it an impressive piece of engineering – all the more so given that it can trace its origins back more than six centuries.

Today rice is inspiring a different sort of technological *tour de force*. In August 2005, the International Rice Genome Sequencing Project published the fruit of 7 years' hard labour: an accurate finished sequence of the almost 400 million base pairs that make up the genome of *Oryza sativa japonica* Nipponbare (http://rgp.dna.affrc.go.jp/IRGSP). The publicly funded project, whose members include academic centres in 10 countries, led by Japan, has built on earlier draft sequences produced by members and the contribution of clones and information from two agribusiness giants, Monsanto and Syngenta. The new sequence provides a wealth of genetic information for plant scientists, accelerating marker-assisted breeding and cloning in a worldwide drive to improve current rice strains. And the close genetic relationship between rice and other cereals means that this information is already helping those at work on maize and wheat as well.

Rice terraces extend for miles
Photo: C.Platt/Panos Pictures

The time is ripe for the rice genome. Three billion people depend on this grain as the cornerstone of their diet, and an estimated 2 billion small-scale farmers and their families rely on it for their livelihoods – 90% of them in the developing world. Rice was a prime beneficiary of the Green Revolution, as new agricultural techniques dramatically increased yields, doubling global production between 1960 and 1990.

But now there are worries that rice, which helped fuel Asia's economic transformation by relieving millions of their hunger, may no longer be able to keep up with rising demand. According to some estimates, world rice production must rise by at least 30% over the next two decades to feed growing, increasingly affluent populations. Yet current rice strains no longer enjoy the yield growth they once did, even on the best land. This is particularly troubling, because urbanization and environmental degradation mean there is less land available to grow rice in the first place.

The future gap between rice supply and demand must be addressed today. Science is central to this effort. Already researchers are using information from the rice genome to understand critical features of the plant, such as flowering time and drought tolerance; the next step is to apply such knowledge to improving the yield and boosting the crop's nutritional value. But cutting-edge science is not enough. Translating these technological advances into real-life benefits for the world's poorest farmers will take money, labour and political will so that the best strains and agricultural practices reach those in greatest need. It is a daunting task, but if people can turn mountains into rice fields, they can win this uphill battle too.

Developing an East Coast Fever vaccine

Genomics is also facilitating significant improvements in fish and livestock vaccine development, for example in East Coast Fever (ECF) in sub-Saharan Africa (see box 3.4). ECF is a long-standing cattle disease that restricts advances in animal-based food production (Mukhebi and Perry

Box 3.4 A new shot at East Coast Fever

Times are changing on the plains around Kajiado in southern Kenya. Maasai herdsmen now have mobile phones, and their wives' brightly coloured shawls and beads say 'Made in Taiwan'. Massive commercial developments are robbing their precious cattle of water and land to graze. But for all this novelty – good and bad – the herdsmen's biggest worry is also one of their oldest: East Coast Fever (ECF).

ECF is a devastating disease of cattle spread by ticks. The parasite responsible – *Theileria parva* – infects lymphocytes, the critical cells of the immune system, causing them to multiply wildly. This proliferation usually kills cattle within a month. Those that survive are stunted, with low milk yields, less draft power and lower fertility. They are also disease carriers, which further diminishes their economic value. Despite its name, the disease has spread far beyond the east coast of Africa where it first appeared more than a century ago. ECF now afflicts 11 African countries, placing an estimated 25 million cattle at risk. More than 1 million animals die of the disease each year.

ECF is a heavy blow to poor herdsmen and small-scale farmers who depend on cattle for their livelihood. Fear of future infection also discourages stockowners from investing in better breeds that would allow them to shift from subsistence husbandry to more lucrative dairy production. Unfortunately, current methods of disease prevention are far from perfect. Chemical protection – in the form of acaricide sprays or dips to kill the ticks – is costly, inconvenient and as bad for the environment as it is for human health. So-called 'infection-treatment', where animals are deliberately infected with *Theileria* and then dosed with antibiotic, can be effective under certain circumstances, but is tricky to deliver, especially where extension services are struggling.

What is needed is a safe and effective vaccine against ECF. One such product may well be available within a decade, thanks to an innovative public–private partnership. These not-for-profit partnerships, which integrate contributions from companies and academic centres and raise money from governments and philanthropic bodies, have already proved successful in developing drugs for neglected diseases of the poor. Now they are being deployed in the battle against ECF.

The British Government is investing £5.1 million (around US$ 9.0 million) in a partnership that includes the International Livestock Research Institute (ILRI), whose years of research on *Theileria* underpin the project scientifically; Merial, a French biotechnology company that is working with researchers at the University of Oxford to produce candidate vaccines and novel delivery systems; and the Kenya Agricultural Research Institute (KARI), which is responsible for conducting field trials of possible vaccines. Researchers reckon that developing a vaccine could cost up to US$ 10 million on top of the US$ 20 million or so spent on *Theileria* research over the past decade. It is a small price to pay when compared with the £300 million in direct costs and economic losses caused by ECF each year.

In July 2005, the vaccine partnership got a boost from another partnership between ILRI and several research centres, including The Institute for Genomic Research (TIGR) in the US. Together they decoded the 8 million-plus base pairs that make up the genome of *T. parva*. This information is already helping vaccine makers to identify novel antigens to test in new subunit vaccines. *Theileria* also shares many genetic features with powerful human pathogens, among them *Plasmodium falciparum*, which causes malaria; and the way *T. parva* transforms bovine lymphocytes also provides insight into how some cancers form. So a better understanding of *Theileria* will not only help in the push for protection against ECF, but also aid in the fight against human diseases. This is one shot the world cannot afford to miss.

Coming soon: a user-friendly vaccine against ECF

Photo: ILRI

1992). Genomics technologies can be used to create recombinant vaccines, which offer considerable advantages over conventional vaccines in terms of safety, specificity and stability. Such advances are also likely to make vaccine production cheaper and improve their availability and accessibility for everyone, thereby bringing significant economic benefits to the smallholder dairy farmers, agro-pastoralists and pastoralists (FAO 2004).

In addition to scientific advances in vaccine development, the fight against ECF is benefiting from innovative partnerships between research organizations, the UK's Department for International Development (DFID) and the private sector to deliver results (McLeod and Randolph 2001). DFID places great emphasis on the role of public–private partnerships in delivering technology to poor producers. By building a product-focused network that cuts across research institutions in new ways, DFID has created a good model for R&D in veterinary products and, perhaps, in products from biotechnologies in general.

Emerging scientific opportunities

There is no doubt that agricultural research has made a considerable contribution to development over the past 50 years. And the process is ongoing; science continues to evolve to tackle currently intractable problems as well as new and emerging issues. One such example is precision farming (or site-specific farming), a fast-developing and exciting approach to crop management. It involves managing within-field variation so that farmers can grow more crops more efficiently at competitive prices while reducing waste to the environment. Precision farming research integrates a group of disciplines including soil science, agricultural engineering, agronomy, remote sensing and geographical information management. It allows farmers to adjust for variability in their fields in characteristics such as soil fertility and weed populations. It uses a global positioning system (GPS) consisting of 24 satellites transmitting signals that define the receiver's location. This system enables farmers to monitor crop yields and guide applications of crop inputs such as fertilizers and herbicides. Precision farming includes yield monitoring, yield mapping, fertilizer application rate control, mapping of weed locations (including spot control), control of spraying rate, topography/boundary mapping and salinity mapping.

It is not just new applications of science that are evolving, but also new approaches to scientific discovery. Two currently emerging areas are nanotechnology and information and communication technology (ICT), which will be considered in this section as a 'taster' of things to come.

Nanotechnology

Nanotechnology essentially involves working with matter at the nanometre scale (1×10^{-9} m); that is, at atomic and molecular levels. It includes the study, design, creation, synthesis, manipulation and application of functional materials, devices and systems, and the exploitation of their properties and phenomena at microscopic levels. The scale may be tiny, but the body of work, size of investments and volume of public dialogue all suggest that nanotechnology is becoming a huge phenomenon. However, serious consideration of the potential of nanotechnology for poor people and developing countries is just beginning. Can poor farmers benefit from this new discipline, can nanotechnology be harnessed to increase agricultural outputs in developing countries and tackle hunger and poverty, and what are the risks?

Recent studies have considered some of the opportunities that nanotechnologies might bring to the poor and to developing countries in the fields of water, energy, food and agriculture, ICT and health (Meridian Institute 2005; Salamanca-Buentello et al. 2005). These opportunities were assessed on the basis of need, direct benefits, appropriateness, feasibility, availability of alternatives, and indirect benefits. Potential risks to human health and the environment as well as ethical, ownership and access issues were also considered. The areas where nanotechnology seems to have most relevance to agriculture include: energy storage, production and conversion, ICT, agricultural productivity enhancement, food processing and storage, and vector and pest detection and management. Details are shown in table 3.1. These opportunities notwithstanding, the main concern highlighted was that these specialized and expensive nanotechnologies may serve to deepen the divide between rich and poor countries. This would happen if nanotechnology became controlled by multinational corporations in developed countries, leading to few benefits for developing countries. Having said that, several developing countries including Argentina, Chile, China, India, Mexico, the Philippines and South Africa have already initiated nanotechnology research programmes.

While scientific advances can usually help, they are not able to provide answers to all agricultural development challenges. Nanoscience and nanotechnology are not silver bullets. Nevertheless, it may prove possible to harness them to address some of the world's most critical development problems (Meridian Institute 2005; Salamanca-Buentello et al. 2005). If that is to happen, it is vital that all concerned groups should have a say early in the development process to prioritize applications and identify any risks, especially those that might affect the hungry and poor in the developing world. While the specifics of this process remain unclear, it will undoubtedly involve innovative partnerships between relevant stakeholders.

Scientist with DNA sequence of rice at the International Rice Research Institute
Photo: H.Netocny/Panos Pictures

Information and communication technologies

Recent years have seen unprecedented advances in ICTs and increasing use of them in developing countries. In particular, the collection of scientific data has seen explosive growth, and now that information needs to be stored, manipulated, analysed, visualized and effectively used. Discussion here will be restricted to bioinformatics and e-agriculture.

Bioinformatics

The 21st century has heralded the era of genomics, with scientists sequencing entire species' genomes including that of humans and rice (see box 3.1, p. 15). Large sequencing projects produce huge

Table 3.1 Applications of nanotechnology most likely to contribute to agricultural development

Nanotechnologies	Examples	Potential applications
Energy storage, production and conversion	• Novel hydrogen storage based on carbon nanotubes • Photovoltaic cells and organic light-emitting devices based on quantum dots • Carbon nanotubes in composite film coatings for solar cells	• Cheaper, clean energy • Low weight, low cost solar cells • Improved rechargeable batteries
Agricultural productivity enhancement	• Nanoporous zeolites for: slow-release and efficient delivery of water and fertilizers for plants; and nutrients and drugs (nano-vaccines) for livestock • Nanocapsules for herbicide delivery • Nanosensors for soil quality and plant health monitoring	More efficient and sustainable food production that requires fewer inputs
Food processing and storage	• Nanocomposites used in plastic film for food packaging • Antimicrobial nanoemulsions for decontamination of food • Nanotechnology-based antigen detection of contaminants	Cheaper, safer food products with longer storage life
Vector and pest detection and control	• Nanosensors for pest and pathogen detection • Nanoparticles for new pesticides, insecticides and insect repellents	More rapid deployment of safer control strategies with reduced losses

Source: Adapted from Meridian Institute (2005) and Salamanca-Buentello et al. (2005)

nucleotide sequences, and the amount of data is rising exponentially; nucleotide databases double in size approximately every 14 months and the number of characterized genes doubles every 2 years. All these data need to be dealt with. This is where bioinformatics comes in. Bioinformatics uses computer algorithms to sort and analyse stored biological data, especially molecular biological information. Using massive computers or networks of computers and increasingly sophisticated collection, storage and analysis programs, bioinformatics enables agricultural scientists to tackle hitherto intractable problems in plant and animal breeding with ease and speed. The bioinformatics portal of the CG Generation Challenge Programme provides links to many public bioinformatics projects contributing vast amounts of data to the internet (see http://www.generationcp.org/bioinformatics.php).

For example, sequencing data generated from the genomes of rice and *Arabidopsis* (a small flowering plant that is widely used as a model organism in plant biology) can form the basis of bioinformatics-based comparative studies with other food crops to aid in their improvement as well. Bioinformatics has helped in the development of cereal varieties with greater tolerance to soil alkalinity and aluminium and iron toxicity and is also contributing to the development of drought-tolerant food crops. Similarly, bioinformatics is facilitating the study of microbes that use carbon dioxide as their sole source of carbon and therefore have the potential to decrease atmospheric carbon dioxide levels and thus combat global warming. The full potential of bioinformatics for science for agricultural development has yet to be realized and needs further exploration.

E-agriculture

E-agriculture is an emerging field at the intersection of agricultural informatics, agricultural development and business. It refers to agricultural services and information that are delivered or enhanced through the Internet and related ICTs. Specifically, it involves the conceptualization, design, development, evaluation and application of new ways of using existing or emerging ICTs. E-agriculture promotes the integration of technology with multimedia, knowledge and culture, with the aim of improving agricultural activities locally, regionally and worldwide. More generally, cheaper ICT can help society reach the MDGs in the areas of education and general poverty alleviation through improved training and education of farmers, livestock keepers, fishers and foresters.

For example, a recent partnership between the United Arab Emirates Agricultural Information Centre (UAE-AGRICENT) and the FAO's World Agricultural Information Centre (WAICENT), resulted in the establishment of the first agricultural information centre in the Middle East (see http://www.fao.org/gil/rdd). The centre provides up-to-date information in Arabic and English on a wide variety of farming, fisheries, forestry and food security topics, including animal genetics, health hazards, safe breeding practices, plant science, and production and natural resource management. The centre will also play a role in issuing early warnings on emergencies such as water shortages and plant and animal disease outbreaks. It will carry information on economic development and agriculture and food security issues and make it readily available to local and regional users. This e-agriculture model also has potential for other developing regions, including Africa and Asia.

However, all these advances and their associated potential must be seen in a global context – and that context, as explained in the next section, is currently changing.

Section 4 The consequences of a changing global environment

The acceleration of progress in science and technology in recent decades should give hope for meeting the MDGs. But just as science and technology are dynamic, so too is the context in which outcomes will be applied. The world is changing in many ways and they cannot all be covered here. Therefore only the two areas that most affect food production and availability for the poor will be considered: climate change and globalization.

Climate change

Climate change is the greatest current threat to the global environment. There is strong evidence that significant global warming is occurring and has already led to changes in the Earth's climate. These include rising air and ocean temperatures, leading to rising sea levels, retreating glaciers and changes to many physical and biological systems. It is likely that most of the warming in recent decades can be attributed to human activities (Houghton et al. 2001). These projected changes will have both beneficial and adverse effects at the regional level on, for example, water resources, agriculture, natural ecosystems and human health (CGIAR 2005b).

Agriculture as influenced by climate change

The anticipated responses of agro-ecosystems to climate change are complex and depend on a number of interacting factors. There will be an effect of enhanced carbon dioxide (CO_2) on crop growth, with differences in C_3 and C_4 plants and important interactions with nutrient availability. (C_3 plants form a pair of three carbon-atom molecules during the first steps in CO_2 assimilation, whereas C_4 plants initially form four carbon-atom molecules.) The growing season at higher latitudes and altitudes will also be affected, as will precipitation patterns – although the predictive capability of models at the regional scale is currently low. Climate change will affect decomposition patterns and thus nutrient availability. In addition, a changing climate will in many instances have a profound effect on the distribution of pests and diseases. The effects will be wide-scale and pervasive (see Rosenzweig and Hillel 1998; Coakley, Scherm and Chakraborty 1999).

Water is already scarce in many places and the demand for irrigation water will rise

Photo: FAO/17125/M.Marzot

Results from studies of the impact of climate change on plant diseases indicate that it could alter the stages and rates of development of pathogens, modify host resistance, and result in changes in the physiology of host–pathogen interactions (Coakley, Scherm and Chakraborty 1999). The most likely consequences are changes in the geographical distribution of hosts and pathogens, thereby altering crop yields and losses, caused in part by changes in the efficacy of management strategies. In the dry lands, rainfed tropics and subtropics, where some crops are near their maximum temperature tolerance, even small increases in air temperature are likely to lead to decreases in yield. This is expected to increase reliance on irrigation, especially in land-scarce areas of developing countries where irrigation is already crucial. Water resources will be a major factor constraining agricultural expansion in South Asia, North Africa and the Near East. All these changes raise research questions both new and old, some of which can be addressed by applying research outcomes from other regions, while others will be solved through the use of new technologies.

Agriculture and forestry influencing climate change

Agricultural systems' relationship with climate change is two-way. Clearing trees for fields and pastures, transforming soil into cultivated land, flooding areas for rice and sugarcane production, burning crop residues, raising ruminant animals, and using nitrogen fertilizers all release greenhouse gases into the atmosphere. Global agriculture is now estimated to account for about 20% of total anthropogenic emissions of greenhouse gases (CGIAR 2005b). Thus, agriculture plays a significant role in climate change.

Deforestation for livestock grazing in Costa Rica

Credit: M.Gill

However, agricultural advances need not have only negative effects on climate change. It is likely that agricultural biotechnologies will improve the efficiency of production systems, decreasing emissions of greenhouse gases. As previously mentioned, there is extensive evidence that yield-increasing agricultural technology has already allowed substantial land savings, thereby containing greenhouse gas emissions. Specifically, the world used about 1.4 billion hectares of land for crops in 1961 and only 1.5 billion hectares in 1998 to get twice the amount of grain and oilseeds. If agricultural technology had been frozen at 1961 levels, cropland would have had to increase from 11% of the planetary surface to 25% to produce the same amount of food as now (Goklany and Trewavas 2003). Yield increase is a specific target of agricultural R&D, one that has been met with outstanding success in many developing countries.

Another significant source of carbon emissions is forest disturbance and clearing. Deforestation results in more than 90% of the above-ground carbon stocks of natural forest being lost. Changes in land use, primarily deforestation in tropical areas (which may or may not be linked to agriculture), currently account for about 20% of global anthropogenic CO_2 emissions (IPCC 2001; Watson et al. 2000). While moving to managed forests may greatly increase yields of timber and wood for fuel, the biomass of these forests is not likely to reach the level in primary forests if there is over- or premature cutting. Conversion of natural forests to plantations also increases carbon emissions. Even though carbon is absorbed by plantation crops, the carbon stocks are usually lower than in the natural forests these crops replaced. Various forestry practices, such as conservation management, storage management and substitution management, can slow down the accumulation of CO_2 in the atmosphere. It is important that forests' contribution to emission reductions, and the associated carbon sources and sinks, are quantified, and that there is a comprehensive analysis of the other environmental and socio-economic criteria that influence forest management (Rudel et al. 2005).

The Intergovernmental Panel on Climate Change estimates that between 1995 and 2050, measures such as reduced deforestation, forest regeneration and increased development of plantations and agroforestry could lead to global carbon sequestration that is equivalent to 12–15% of the carbon emissions from fossil fuels. This – together with higher yields of food and forest products – is achievable through research-based forestry and agricultural intensification (FAO Committee on Forestry 2001).

Consequences for research

Climate change is likely to result in profound changes for small-scale farmers who rely on rainfed production systems to feed families and livestock. Subsistence farmers will be particularly vulnerable to change because they lack the resources to adopt alternative livelihood strategies. Science can help, however. Among the most important technological changes will be improved crop cultivars and cropping practices, which will raise yields. Factors such as the spread of no-till/conservation agriculture and the expansion of irrigation will further help to reduce the sensitivity of some systems to climate change. Many such measures needed to reduce or adapt to climate change will also help with other problems, such as water/air pollution, soil erosion and vulnerability to droughts or floods. Research priorities include:

Grazing may get even scarcer with climate change

Credit: M.Gill

- Development of crop/forage varieties resistant to drought, flooding, high temperatures, salinity and pests/diseases, using both biotechnology and conventional plant breeding techniques. The development of dual-purpose crops should be emphasized, especially in mixed farming systems
- Promotion of agroforestry systems to increase ecosystem resilience, maintain biodiversity and increase carbon sequestration
- Improvement and promotion of livestock breeds better adapted to drought, high temperatures and diseases
- Development of climate models to analyse how climate change will affect crop production. An early understanding of these effects will give time to develop suitable alternatives. An example is the ILRI–CIAT maize model
- Development of improved land-use systems including forest regeneration to restore degraded lands, stabilize slopes and reduce the risk of soil erosion
- Management regimes for crop residue and livestock waste
- Development of sustainable forest management systems.

Globalization

Advances in transportat infrastructure and ICT, coupled with enabling policies such as market liberalization, privatization and decentralization, have resulted in an explosive growth in trade and foreign direct investment, greater integration of developing countries' economies into world markets, and a proliferation of new actors in the globalization process.

Today's marketplace is global as well as local

Photo: J.Wong

All this has affected agriculture through changes in food demand and supply. Rising incomes and falling staple crop prices have enabled consumers to demand more quality and greater diversity in their food choices. Secondly, higher-income consumers have become more demanding with regard to the food safety and ethical ramifications of current food production processes. Producers have responded by investing in technological innovations that can meet these new demands. And with more trade, competition among producers has intensified, resulting in producers having to adopt new technologies to maintain their competitiveness in world markets. This has affected farmers in developing countries as well as developed ones, as increased global trade has connected them with other producers and consumers worldwide.

Consequences for research

Globalization has had an impact not only on the demand for agricultural research but on its supply as well. It has highlighted comparative advantages regionally and internationally, and helped bring research to where it is lacking. New participants in the private research sector have also emerged, following the introduction of incentives in the 1980s and 1990s in the form of intellectual property rights (IPRs). This has made the agricultural R&D environment increasingly competitive and proprietary. Other new actors participating in the new era of international agricultural R&D include NGOs and farmer organizations.

Section 5 The enabling environment for research: a changing international landscape

The pay-offs to past investments in agricultural R&D have been high the world over. Importantly, there is no evidence that the returns to investments have diminished over time, implying that equally large returns to current R&D spending are feasible in the future (Alston et al. 2000). On the face of it, this suggests that societies would be better-off investing more in agricultural research, but there are a whole host of critical public policy questions that go beyond simply the amount spent on the agricultural sciences. These include: precisely how much should be spent on specific types of R&D; who should pay for and conduct the research; how are the strengths and objectives of research systems changing; and are regulatory mechanisms a help or a hindrance? Not all of these questions can be addressed here, but we will start with a new analysis of the current and prospective investment trends for agricultural R&D worldwide, based on data from 1981 to 2000.

Total science spending

Agricultural R&D is not conducted in isolation from the rest of science. There is a long history of agricultural scientists drawing on and adapting findings from the basic biological, chemical and other sciences to further their own research (Pardey and Beintema 2001). Moreover, contemporary developments (particularly in the genetic and information sciences) serve to blur the boundaries between agriculture and the rest of the sciences. Therefore, putting the agricultural sciences in the context of science spending overall is instructive.

In 2000, the world invested a total of $725 billion (in international dollars)[1] in all the sciences, including both public agencies and private firms. This is about 1.7% of the world's $43.8 trillion GDP and nearly one-third more than was spent on R&D just 5 years earlier (table 5.1). After accounting for inflation, real spending in all regions of the world increased from 1995 to 2000, with one disturbing exception. At $3.2 billion, total spending in 2000 on all the sciences throughout all of sub-Saharan Africa was less than the nearly $3.5 billion invested just 5 years earlier (for more on that see IAC 2004). The most notable increases were for the Asia and Pacific region, which grew its investment level by 12.3% per year over 1995–2000, followed by West Asia and North Africa, which grew annually by 4.5%, mainly driven by Israel and Turkey.

These regional trends hide a profoundly disturbing reality: that there is evidence of a large and, in places, growing divide between the scientific haves and have-nots. For example, the overall growth in the Asia and Pacific region masks the fact that just two countries – China and India – accounted

[1] Data in this sub-section are based on Pardey and Dehmer (2005). See box 5.1 for more details on the methods used to deflate and convert expenditures denominated in current local currency units to a common baseline. Hereafter in the text of Section 5, all currency values are expressed as international dollars unless explicitly stated otherwise.

Box 5.1. Internationally comparable measures of R&D

Cross-country comparisons of R&D expenditure, like most international comparisons of economic activity, are confounded by substantial differences in price levels among countries. This is particularly a problem when valuing something like expenditure on agricultural R&D, where typically two-thirds is spent on local scientists and support staff, not capital or other goods and services that are commonly traded internationally. For example, the average salary (net of benefits) received by full professors working at large public universities in the US in 2004–2005 was US$ 88,457. A comparable annual salary paid to a chief scientific officer in Bangladesh working for the Bangladesh Agricultural Research Institute (BARI) – the Government's main agency – was TK 20,700. This is equivalent to 1,683 international dollars when converted using purchasing-power parity (PPP) rates or US$ 316 using official exchange rates. At Brazil's national institute, the Empresa Brasileira de Pesquisa Agropecuária (Embrapa), a mid-career senior scientist working at the same time earned an average of 72,348 Reals, which is the equivalent of 65,705 international dollars or US$ 30,020.

Converting research expenditures from different countries to a single currency using official exchange rates tends to understate the quantity of research resources used in economies with relatively low prices, while overstating the quantity of resources used in countries with high prices. A country's international price level is the ratio of its PPP rate to its official currency exchange rate into US dollars. In other words, it is an index of the costs of goods in one country relative to the same bundle of goods in a numeraire country; in this case the US. At present, there is no entirely satisfactory method for comparing consumption or expenditures among countries at different points in time (or for that matter, at the same point in time). Unfortunately, the choice of deflator and currency converter can have substantial consequences for both the measure obtained and its interpretation.

Most of the research expenditures in this report are denominated in 2000 'international dollars' using PPPs to do the currency conversions.[2] For convenience of interpretation, the reference currency – here an international dollar – is set equal to a US dollar in the benchmark year.

for 86% of the $44.2 billion increase in regional spending from 1995 to 2000. Put another way, China and India accounted for 60% of the region's scientific spending in 1995, jumping to 72% by 2000. In contrast, research spending in the six Pacific countries (including Fiji, French Polynesia, New Caledonia and others) grew by only 1.1% a year from 1995 to reach only $164 million in 2000 (representing 0.17% of the regional total).

Trends in sub-Saharan Africa between 1995 and 2000 are striking: out of 48 countries, 40 increased their spending on total science during this period. Yet between these years, aggregate investment for the region declined by 7.3%. The majority of this is accounted for by a 63% decline in total science spending by South Africa. Indeed, South Africa represented 63.8% of the regional total in 1995 and only 37.6% in 2000.

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[2] The currency conversion procedure is described more fully in Pardey, Roseboom, and Craig (1992). Research expenditures in current local currency units are first deflated to a base year set of prices (2000, in this case) using a local price deflator, and then converted to a common currency unit (specifically, international dollars) using PPPs for 2000 obtained from the World Bank (2005) rather than the more familiar official exchange rates.

Table 5.1 Total gross domestic expenditures on research and development, 1995 and 2000

	Total expenditure (million 2000 international dollars)		Shares in global total (percentages)	
	1995	2000	1995	2000
Asia and Pacific (26 countries)	51 825	96 011	9.4	13.2
China	19 348	48 300	3.5	6.7
India	11 674	20 740	2.1	2.9
Latin American and Caribbean (31 countries)	18 038	22 283	3.3	3.1
Brazil	9 771	13 034	1.8	1.8
Sub-Saharan Africa (43 countries)	3 487	3 242	0.6	0.4
West Asia and North Africa (18 countries)	7 456	12 980	1.4	1.8
Other developing countries (21 countries)	17 311	21 742	3.1	3.0
Subtotal, developing countries (139 countries)	**98 117**	**156 258**	**17.8**	**21.5**
Japan	82 725	98 606	15.0	13.6
United States	197 080	261 471	35.8	36.0
Subtotal, high-income countries (28 countries)	**452 619**	**569 209**	**82.2**	**78.5**
Total (167 countries)	**550 736**	**725 467**	**100.0**	**100.0**

Source: Based on Pardey and Dehmer (2005) using data from numerous published and online sources.

Notes: High-income countries includes most countries in the OECD as well as non-OECD high-income countries, such as Singapore.

All data were collected in or converted to current local currency units, then deflated to 2000 constant currency units, and then finally converted to international dollars using purchasing power parity (PPP) exchange rates.

This bifurcation in science spending is more widespread. For example, Brazil's share of the Latin American total grew from 54 to 58% from 1995 to 2000. The rich countries have not followed that same pattern. The US and Japan accounted for 63% of the total in the Organisation for Economic Cooperation and Development (OECD) countries in 2000, essentially the same as their 1995 share. This suggests a more even rate of growth in scientific spending among the developed countries than among countries in the developing regions of the world.

These new data make manifestly clear the significant spatial concentration of science spending worldwide. In 2000, the top five countries (in descending order, the US, Japan, Germany, France and the UK) accounted for 68% of the world's science spending. Expanding this group to the top 10 countries, encompassing Italy and Canada along with the large, lower-income but faster growing countries of China, India and South Korea, takes the share up to 81.4% of the world total scientific investment. Moreover, the share of the bottom 80 countries (accounting for nearly 7% of the world's population in 2000 but only 1.7% of global GDP) slipped from 0.36% of the global total in 1995 to 0.33% in 2000. This indicates a large and sustained gap between a comparatively small group of scientific haves, and a substantial group of scientific have-nots.

Agricultural R&D spending

Public research trends

Worldwide, public investments in agricultural research have increased by 51% in inflation-adjusted terms over the past two decades; from an estimated $15.2 billion in 1981 to $23 billion in 2000 (table 5.2). These data reveal a historical first: during the 1990s, developing countries as a group undertook more of the world's public agricultural research than developed countries. The Asia-Pacific region has continued gaining ground, accounting for an ever-larger share of the developing-country total since 1981. Just two countries from this region, China and India, account for 39% of the developing world's expenditure on agricultural R&D in 2000, a substantial increase from their 22.9% combined share in 1981. In stark contrast, sub-Saharan Africa has continued to lose market share, falling from 17.3% to an 11.4% share of the developing-world total between 1981 and 2000. When spending patterns for all the sciences are compared, it becomes clear that agricultural R&D has become increasingly concentrated in a handful of countries worldwide. Just four countries – the US, Japan, France and Germany – accounted for two-thirds of the public research done by rich countries in 2000, about the same as two decades before. Similarly, five developing countries – China, India, Brazil, Thailand and South Africa – undertook 53.3% of the developing world's public agricultural research in 2000, up from 40% in 1981. Meanwhile, 6.3% of the agricultural R&D worldwide was conducted across 80 countries, home to some 625 million people (table 5.3).

The estimates in table 5.2 reveal a patchwork pattern of growth. More recent rates of increase in inflation-adjusted spending for all developing regions of the world fail to match the rapid ramping up of public agricultural R&D spending that Pardey and Beintema (2001) reported for the 1970s. However, this is not true everywhere. The growth in spending for the Asia–Pacific region rebounded in the 1990s from the slower rates of growth observed in the 1980s. This was especially so in China and India during the 1996–2000 period, when a range of government policies began to revitalize public research and improve its commercialization prospects, including linkages with the private sector (for more details on India see Pal and Byerlee in press, and for China see Fan, Qian and Zhang in press). Spending growth throughout Latin America as a whole was more robust during the 1990s than the 1980s, although the recovery was more fragile and less certain for some countries, such as Brazil (where there was in fact a contraction in spending at the close of the 1990s).

Table 5.2 Total public agricultural research and development spending by region, 1981–2000

	Agricultural R&D spending (million 2000 interational dollars)			Shares in global total (percentages)		
	1981	1991	2000	1981	1991	2000
Asia and Pacific (28 countries)	3 047	4 847	7 523	20.0	24.2	32.7
China	1 049	1 733	3 150	6.9	8.7	13.7
India	533	1 004	1 858	3.5	5.0	8.1
Latin America and Caribbean (27 countries)	1 897	2 107	2 454	12.5	10.5	10.8
Brazil	690	1 000	1 020	4.5	5.0	4.4
Sub-Saharan Africa (44 countries)	1 196	1 365	1 461	7.9	6.8	6.3
West Asia and North Africa (18 countries)	764	1 139	1 382	5.0	5.7	6.0
Subtotal, developing countries (117 countries)	**6 904**	**9 459**	**12 819**	**45.4**	**47.3**	**55.8**
Japan	1 832	2 182	1 658	12.1	10.9	7.2
USA	2 533	3 216	3 828	16.7	16.1	16.6
Subtotal, high-income countries (22 countries)	**8 293**	**10 534**	**10 191**	**54.6**	**52.7**	**44.2**
Total (139 countries)	**15 197**	**19 992**	**23 010**	**100.0**	**100.0**	**100.0**

Source: Pardey et al. (2005) based on data from the Agricultural Science and Technology Indicators (ASTI), available at http://www.asti.cgiar.org/.

Note: The high-income countries total excludes a number of high-income countries such as South Korea and French Polynesia (which have been grouped into the Asia and Pacific total), Bahrain, Israel, Kuwait, Qatar, United Arab Emirates (grouped in West Asia and North Africa), and Bahamas (Latin America and Caribbean). To form these regional totals we scaled up national spending estimates for countries that represented 79% of the reported sub-Saharan Africa total, 89% of the Asia and Pacific total, 86% of the Latin America and Caribbean total, 57% of the West Asia and North Africa total, and 84% of the high-income total.

Overall, investments in agricultural R&D in sub-Saharan Africa failed to grow by more than 1% per year for the whole of the 1990s. This is a continuation of a longer-run slowdown observed by Pardey and Beintema (2001). Even more disturbing is the fact that about half of the 27 African countries for which we have national total estimates spent less on agricultural R&D in 2000 than they did in 1991. Another feature of agricultural R&D in Africa is the great variation between countries in terms of the percentage contribution from development aid (see figure 5.1 on p. 37).

A notable feature of the growth trends in table 5.2 is the contraction in support for public agricultural R&D among rich countries. While spending in the US picked up in the latter half of the 1990s

Table 5.3 Spatial concentration of public agricultural R&D spending worldwide, 1995 and 2000

Country groups	1995	2000	2000 GDP	2000 Population
	(percentages)			
Top 5	50.6	50.0	52.6	51.8
Top 10	65.7	62.4	66.5	56.1
Bottom 80	9.2	6.30	5.7	11.3

Source: Pardey et al. (2005) based on data from ASTI, available at http://www.asti.cgiar.org/.

Note: The top 10 agricultural R&D spending countries (in descending order) in 1995 were the United States, Japan, China, India, Brazil, Germany, South Korea, Australia, the United Kingdom and France. In 2000, the listing was the United States, China, India, Japan, Brazil, Germany, Australia, South Korea, United Kingdom and Canada.

compared with the first part of the decade, there was a massive reduction in funding of public research in Japan (and also, to a lesser degree, several European countries) toward the end of the 1990s, leading to a decline in rich-country spending as a whole for the decade. Once again, these new data reinforce longer-run trends observed earlier – namely that there has been a fairly widespread scaling back or, at best, a slowing down of support for publicly performed research-for-agriculture among rich countries. In part, this points to a shifting emphasis from public to privately performed agricultural R&D, but also to a shift in government spending priorities.

Inevitably, this will affect productivity prospects in agriculture for the countries in question. And, as Pardey, Alston and Piggott (in press) suggest (and as was discussed in Section 2 of this report), a more subtle and arguably more important consequence is that slowdowns or cutbacks in rich-country spending will curtail the future spillover of ideas and new technologies from rich to poor countries. These rich–poor country linkages will be even weaker if the funding trends proceed in parallel with other policy and market developments, such as the strengthening of IPRs and biosafety regulations. There is another factor that seems to compound these developments: that rich-country R&D is orienting away from productivity gains in food staples toward concerns over the environmental effects of agriculture as well as food quality and medical, energy and industrial applications of agricultural commodities. With developed countries as a group still accounting for 44% of public agricultural R&D worldwide (and more than 80% of all science spending), the long-term consequence of these trends may be a significant slowdown in productivity gains for food staples.

The broad trends documented here gloss over many of the aspects of agricultural R&D funding that have important practical consequences. For example, variable or unpredictable research funding is especially troublesome for agricultural R&D given the long gestation period for new crop varieties and livestock breeds. It also undermines the long-term employment prospects for scientists and other staff (Pardey, Alston and Piggott in press). Variability encourages an over-emphasis on short-term projects or those that have a short lag between investment and outcome – and adoption. It also discourages specialization of scientists and other resources in areas of work where sustained funding may be uncertain, even when these areas have high pay-off potentials.

Public- versus private-sector efforts

Table 5.4 points to a large private presence in agricultural R&D, but there is a dramatic difference between rich and poor countries and among individual countries. In 2000, the total global spending on agricultural R&D (including pre-, on- and post-farm oriented R&D) was $36.5 billion – about 37% of which was performed by private firms, the remaining 63% coming from public agencies. Notably, about 94% of that private R&D was performed in developed countries, where on average some 55% of agricultural R&D is private. In developing countries, only 6.3% of agricultural R&D is undertaken privately, although there are large disparities in the private share among regions of the developing world. In the Asia–Pacific region, for instance, around 8% of the agricultural R&D is private, compared with only 2% throughout sub-Saharan Africa. The majority of private R&D in sub-Saharan Africa is oriented to crop improvement research, often (but not always) dealing with export crops, e.g. cotton in Zambia and Madagascar and sugar cane in Sudan and Uganda. Virtually all the private firms are small, both in terms of total spending and numbers of researchers. They involve a mix of locally owned companies (e.g. Pannar Seeds in Greytown, South Africa, or Kenana Sugar Company in the White Nile State, Sudan) and local affiliates of multinational companies. Moreover, almost two-thirds of the private research performed throughout the whole region was done in South Africa. Given the tenuous market realities facing much of African agriculture, it is unrealistic to expect especially marked or rapid development of locally conducted private R&D. That said, there may be substantial potential for tapping into private agricultural R&D done elsewhere through creative public–private joint venture arrangements.

Development aid and agricultural R&D

Development aid has been an important source of funding for agricultural R&D – including CGIAR research – and has also played a pivotal part in underwriting national R&D efforts in some

Table 5.4 Public and private agricultural research and development totals, circa 2000

	Expenditure (millions 2000 international dollars)			Share (%)		
	Public	Private	Total	Public	Private	Total
Developing countries	12 819	869	13 688	93.7	6.3	100
Developed countries	10 191	12 577	22 767	44.8	55.2	100
Total	**23 010**	**13 446**	**36 456**	**63.1**	**36.9**	**100**

Source: Pardey et al. (2005) based on data from ASTI, available at http://www.asti.cgiar.org/.

parts of the world, especially in sub-Saharan Africa. Piecing together a coherent picture of general trends in the aid–agricultural R&D relationship is hampered by limited access to data. Here we present some relevant evidence, mindful of the partial picture it provides.

From 1960, official development assistance (ODA) from the Development Assistance Committee countries rose in real terms to reach a peak of $72.6 billion in 1992. By 2001 it had dropped to $51.2 billion, but then increased to $74.5 billion in 2004. There has been no clear shift in the share of ODA accounted for by bilateral assistance, which averaged 70% of total aid during the 1990s (table 5.5). Data showing the sectoral breakdown of aid are available for bilateral but not multilateral funds. The data we do have suggest a strong shift away from agriculture in aid funding priorities. In the latter half of the 20th century, the agricultural component of bilateral assistance grew steadily, to peak at $6.5 billion in 1988, or 15.2%, declining thereafter to $2.0 billion (4.2%) in 2003.

Aid for agricultural R&D in Africa

The era of substantial donor support for agricultural R&D in sub-Saharan Africa appears to be drawing to a close, at least for now. Donor contributions (including World Bank loans) accounted for an average of 35% of funding to principal agricultural research agencies in 2000 (Beintema and Stads 2004). Five years earlier, close to half the agricultural research funding of the 20 countries for which time-series data were available was derived from donor contributions (figure 5.1).

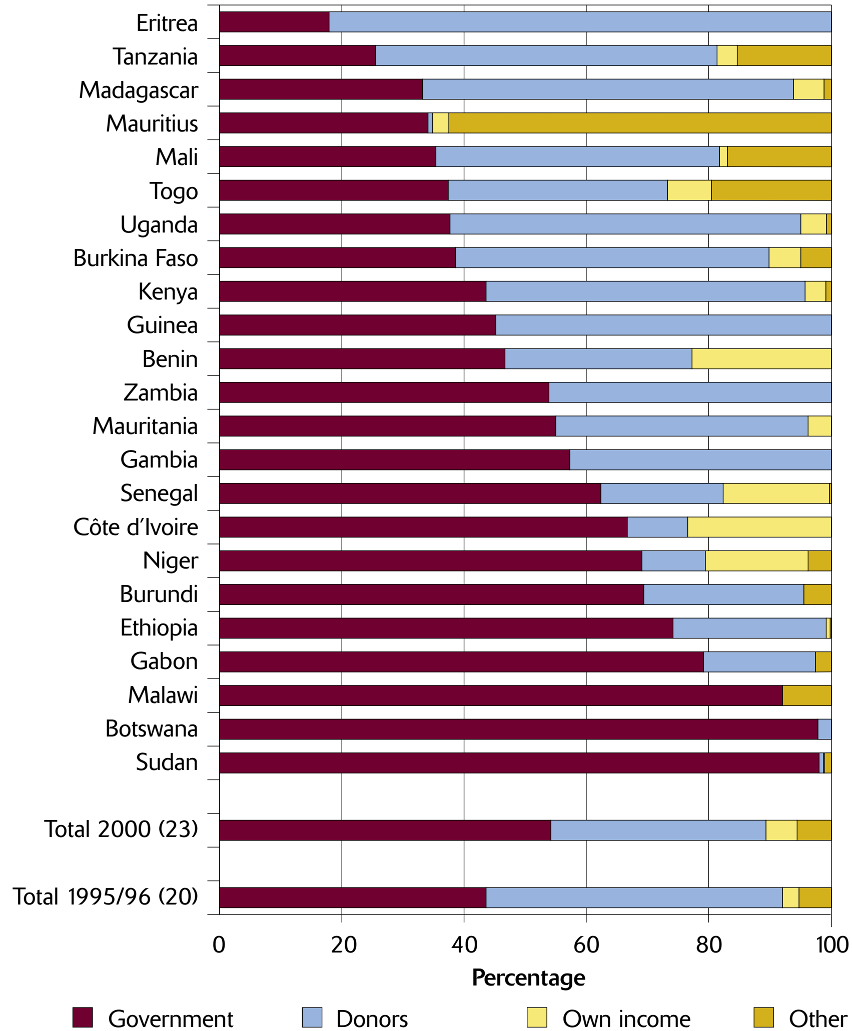
Table 5.5 Agriculture's share of overseas aid

		Bilateral aid	
Year	Total ODA (in 2000 US$ millions)	Amount (in 2000 US$ millions)	Share to agriculture (%)
1970	24 719	20 886	4.91
1975	35 448	26 233	11.13
1980	49 166	31 875	16.63
1985	41 773	30 782	15.93
1990	67 071	47 540	11.39
1995	64 077	44 129	9.82
2000	53 749	36 064	6.36
2003	65 502	47 222	4.22
2004	74 483	50 700	n.a.

Source: Adapted from Pardey, Alston and Piggott (in press, Chapter 12).

Note: ODA – Official development assistance, n.a. indicates not available

Figure 5.1 Sources of funding by country, 1995/96 and 2000



Source: Beintema and Stads (2004).

Notes: Funding data include only the main agricultural research agencies in each of the respective countries. Combined, these agencies accounted for 76% of total spending for the 23-country sample in 2000. Data for West Africa, with the exception of Nigeria, are for 2001.

These regional averages mask great variation among countries. In 2000, donor funding accounted for more than half of the agricultural R&D funding in 7 of the 23 sample countries. Eritrea, in particular, was highly dependent on donor contributions; its principal agricultural research agencies received more than three-quarters of their funding from donors. In contrast, donor funding was quite insignificant in Botswana, Malawi, Mauritius and Sudan (less than 5%). In terms of donors' share of total agricultural R&D funding, from the mid-1990s to 2000, a third of the 20 countries in our time-series sample experienced declines of 10% or more, while only four countries experienced an increase of at least 10%. Notably, donor funding fell from more than 50% of total funding to 10% or less for Malawi, Niger and Sudan as major projects, funded by World Bank loans with contributions from the FAO, were completed.

Funding from sources other than government or donors, such as internally generated revenues, was comparatively small – representing just 11% of total funding in 2000. The exceptions are Benin and Côte d'Ivoire. The principal agricultural research agencies in these two countries generated significant shares of total funding from research contracts, commercialization of agricultural products and dissemination of research results. In some cases, this practice was dictated by the terms of the international loans for agricultural R&D. For example, in Côte d'Ivoire, the World Bank's second National Agricultural Services Support Project (PNASA II) had an important commercialization component, stipulating that 35% of the annual budget of the National Agricultural Research Centre was to be self-generated through mechanisms such as commodity sales (Beintema and Stads 2004).

CGIAR trends

While the CG system has captured the attention of the international agricultural R&D and aid communities through the impact of its scientific achievements and its pivotal role in the Green Revolution, it accounts for only a small fraction of the global agricultural R&D expenditure. In 2000, the CGIAR contributed 1.5% of the $23 billion (2000 prices) global public-sector investment in agricultural R&D and just 0.9% of all public and private agricultural R&D spending.

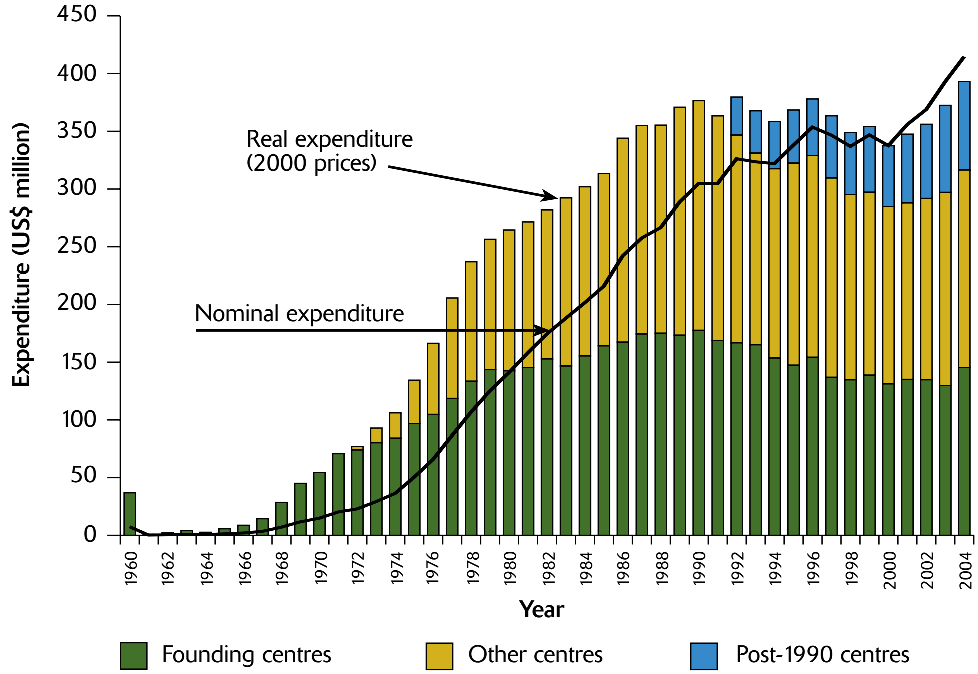
Figure 5.2 plots the nominal and real (that is, adjusted for inflation) values of total expenditures for the CGIAR. The CG system began modestly: between 1960 and 1964, of the institutes that would become the CG, only IRRI was operating as such. By 1970, the four founding centres – IRRI, CIMMYT, the International Institute of Tropical Agriculture (IITA) and the International Center for Tropical Agriculture (CIAT) – were allocated a total of $14.8 million a year.

Over the next decade to 1980, progressive expansion of the total number of centres and the funding per centre resulted in a 10-fold increase in nominal spending to reach $141 million. Spending continued to grow during the 1980s, more than doubling in nominal terms to reach $305 million in 1990. During that decade, however, although the number of centres grew from 13 to reach 18 at one point (there are now 15), funding did not grow in line to maintain the level of spending per centre or the overall growth rate. Since 2000, funding has grown in total but there is a continuing trend towards earmarking support for specific projects and programmes that involve multiple centres or other research providers outside the CG.

National agricultural research systems

The previous paragraphs describe the changes in the CG system over the decades since its establishment. Unfortunately, it is not possible to undertake a similar exercise in relation to the national agricultural research systems (NARSs) in developing countries, but what this section does is to draw attention to some of the recent changes both in the systems themselves and in the demands

Figure 5.2 Nominal and real expenditures of CGIAR-supported centres



Source: Adapted from Pardey, Alston and Piggott (in press, Chapter 12).

Note: Expenditures pre-1972 represent funds to precursor international research institutes: The International Rice Research Institute (IRRI) from 1960, the International Maize and Wheat Improvement Center (CIMMYT) and the International Center for Tropical Agriculture (CIAT) from 1966, and the International Centre for Tropical Agriculture (IITA) from 1971. Real expenditures are nominal expenditures deflated to base year 2000 prices.

placed on them. These days the focus is on systems rather than on national agricultural research organizations (NAROs). In addition to NAROs, NARSs now embrace universities, the private sector (both for profit and non-profit), regional and sub-regional organizations (ROs and SROs respectively), NGOs and farmers' organizations (Byerleee, Alex and Echeverría 2002). Indeed, others actors – such as policy makers in various ministries – may crucially determine major issues affecting agricultural development.

NARSs are facing unprecedented challenges that are proceeding in different ways at different speeds across regions and countries. ROs have evolved to strengthen the influence of small NARSs within global networks. For example, the Global Forum for Agricultural Research (GFAR) supports five regional initiatives: the Forum for Agricultural Research in Africa (FARA), the Asia-Pacific Association of Agricultural Research Institutions (APAARI), the Forum for the Americas on Agricultural Research and Technological Development (FORAGRO), the Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), and the Central Asia and the Caucasus region (CAC). Within these regions, organizations and institutions exist based on the specific needs of the sub-region.

The concept of the NARS has also been broadened to provide focus on national agricultural innovation systems, which serves to highlight the purpose of research (to generate agricultural innovation) as well as acknowledging the contributions of actors such as farmers and NGOs. This dynamic evolution is taking place at a time when, as has already been noted, investment in agricultural research in the majority of countries is falling. This is a result of both the weak fiscal situation of many developing countries and the perception that the State does not need to invest in producing public goods related to agricultural production and rural development. Some countries are going so far as to replace core budget support for agricultural research with competitive grants. This trend undermines capacity-building activities at a time when new developments in science require advanced training of researchers in order to take advantage of them.

Another impact of reduced budgets is to undermine the effectiveness of national agricultural research institutes (NARIs). Retiring senior scientists are not being replaced and there is less investment in graduate-level advanced training. As a consequence, in new areas of science such as biotechnology, agro-ecology and informatics, it is not the NARIs that are building scientific capacity but rather other institutional actors, such as research centres related to science academies and universities.

The increasing role of partnerships led by NARS

Some developing countries are, however, positioning themselves to secure maximum benefits from agricultural biotechnologies through new initiatives and partnerships. One example is Biosciences eastern and central Africa (BecA), which is endorsed by the Steering Committee of the New Partnership for Africa's Development (NEPAD). BecA supports development and application of bioscience research and expertise to produce technologies that help poor farmers reduce risk, secure assets, improve productivity and income, and increase market opportunities. It provides a focal point so that the scientific community in eastern and central Africa can support the activities of national, regional and international agencies as they address important agricultural problems related to alleviating poverty and promoting development. BecA is seeking a range of partnerships with research, education and training institutions both within Africa and, through linkages with the international scientific community, the private sector. By establishing a communications strategy, it will strengthen links with rural and urban communities, women's groups, consumers in Africa, the scientific community, prospective investors and the media. In particular, BecA is focusing on realizing the potential of women and young people in agriculture, science and technology in Africa. The crops and livestock important to the well-being of women will receive particular attention (further information is available at http://www.biosciencesafrica.org).

Building partnerships and institutional linkages between private and public sectors for agricultural biotechnology will accelerate and maximize the benefits for developing countries. The African Agricultural Technology Foundation (AATF; for more information see http://www.aatf-africa.org) was recently established with the aim of removing barriers that prevent small-scale farmers in Africa from gaining access to existing agricultural technologies, especially biotechnologies. The

AATF facilitates partnerships between private-sector companies such as Monsanto, Pioneer, Syngenta, etc. and public-sector institutes so that existing and new biotechnologies can be applied to address some of the serious biotic constraints that reduce the yield of important food crops. Current projects include cowpea, cassava and banana productivity improvement (including disease and pest resistance). The AATF is likely to play an increasingly important role in the future as more and better agricultural biotechnologies are made available by private companies.

Cassava is one of the crops that could benefit from public–private biotechnology partnerships
Photo: J.Esser

Intellectual property rights: implications for NARS and the CGIAR

One central issue that needs to be resolved early on in any partnership is how IPRs will be treated. The 1993 agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization (WTO) requires all WTO members to implement effective legal protection for intellectual property (Louwaars et al. 2005). The purpose of intellectual property (IP) protection is to stimulate and reward research and increase societal welfare. However, the mechanism by which this is achieved – effectively granting a monopoly – may work against some stakeholders. This potential disadvantage can be mitigated if a stakeholder is aware of how various IP systems operate worldwide and what changes expanded IPRs will bring to NARSs in developing countries.

There is, as yet, no single source of information available that lists IP/technology of potential value to developing country agriculture. However, several international initiatives are being established. In the US, an organization called Public Intellectual Property Resource for Agriculture (PIPRA) is developing a database of agricultural biotechnology associated with its members that will be searchable through a web-based interface. In 2006 a new, Europe-based initiative will commence. Epiagri – supported by the European Commission – will merge a number of public-sector sources of agricultural IP in a range of cooperative activities including a shared database for IP and technology, which will also be searchable. In Australia, the Biological Innovation for an Open Society (BIOS) initiative is the creation of the Center for the Application of Molecular Biology to International Agriculture (CAMBIA). BIOS provides on-line access to an extensive patent database, IP tutorials, guides to IP policies and practices, and information on the countries in which patents have been filed. These tools assist the user in determining which IP is free to use in which countries – and which is not.

Given that the ground rules and technologies are complex and changing, several intermediaries have emerged to facilitate understanding, dialogue and eventually technology transfer. These include the AATF referred to above. Not only will the AATF offer its partners access, usually on a royalty-free basis, to advanced agricultural technologies that are privately owned by companies and other research institutions, it will also provide the matchmaking, stewardship and guidance at all levels to ensure the development of successful projects, carried out in responsible ways (Toenniessen and Delmer 2005).

Section 6 Conclusions and key messages

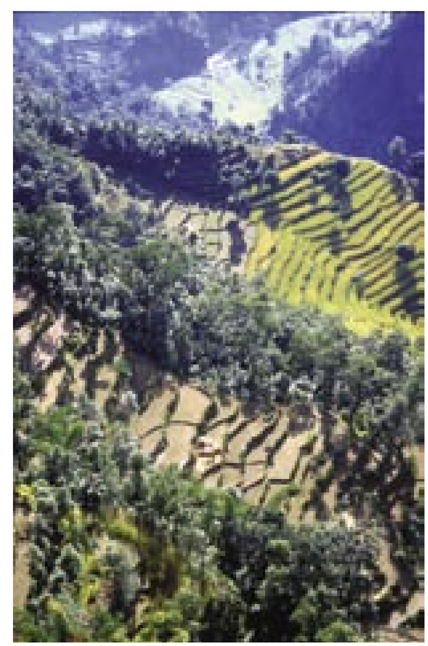
This report shows that science for agricultural development has an impressive track record of delivering benefits to farmers and consumers through new crop, livestock, fish and forest technologies that improve productivity and producers' incomes. Goklany (1998) estimated that, in 1961, global agriculture used 4.4 billion ha of land. By 1993, this had increased by only 380 million ha to 4.8 billion ha. Without the development and application of agricultural research and technology this area would be at least 3.5 billion ha larger – the extra land needed to feed our 1993 population at 1961 yields.

This report also highlights new opportunities offered by cutting-edge science such as genomics, nanotechnology and ICT (Section 3) that will continue to deliver benefits to help the global community meet the MDGs in a rapidly changing world (Section 4). This requires taking into account the roles of the different players in the institutional system (Section 5) as well as improving the monitoring of factors that facilitate successful impact (Section 2).

As never before, the R&D community is now positioned to sustain and enhance past investments so that technology flows faster through the pipeline and more options are delivered to users. This has real potential to help the poor and hungry, as long as there is sustained and enhanced investment in science for agricultural development.

However, as Section 5 revealed, there are substantial and potentially profound global changes under way. In particular, there is a bifurcation in the conduct of agricultural R&D, with a select few developing countries – China, India and Brazil – beginning to close the gap on the developed countries, with their higher investment levels and research intensities. In contrast, an increasing number of developing countries, especially in Africa, are slipping back in terms of the amount spent on agricultural R&D. It is vital that poor countries that rely on agriculture reverse this trend.

This emphasizes the importance of the 8th MDG – developing a global partnership – for making a real difference in terms of reducing poverty and hunger, improving education and health and protecting the world's natural resources. Successful partnerships require mutual understanding between the partners – a never-ending saga, especially in a world of rapidly changing contexts. In this respect it is relevant to note recent developments in the strategy of the CGIAR, which, as part of its effort to build partnerships, has identified five priority areas (box 6.1) through a process of wide consultation. Other bodies may have different priorities, but by exchanging such information and developing a mutual understanding of aims and objectives, some of the synergies inherent in partnerships may be captured.



Intensive land use in Nepal: rice terraces and fodder trees

Photo: M.Gill

Box 6.1 The CG's five priority areas for research

- Sustaining biodiversity for current and future generations (MDGs 1, 4, 5,7 and 8)
- Producing more food at lower cost through genetic improvements (MDGs 1, 3, 4, 5, 6, 7 and 8)
- Creating wealth among the rural poor through high-value commodities and products (MDGs 1, 3, 4, 5 and 7)
- Combining poverty alleviation with sustainable management of water, land and forest resources (MDGs 1, 3, 4, 5, 7 and 8)
- Improving policies and facilitating institutional innovation to support sustainable reduction of poverty and hunger (MDGs 1, 3, 4, 5, 6, 7 and 8)

Generic conclusions

This report has illustrated how research has had a lasting impact on agricultural development and how it has the potential to have an even greater impact in the future. In order to achieve this it will be important that all actors in the R&D process – from research design (which needs to consider the context in which outcomes will be applied) through to those who will apply the outcomes in the field – should communicate with each other and should have equal access to knowledge. This needs to be understood in the context of a world that is rapidly changing as a result of processes such as climate change and globalization; changes that add to the already considerable challenges posed by the task of delivering relevant outcomes from research. The flip side of these problems is the speed of progress in science (e.g. genomics) and technology (e.g. ICT), which compensates by making some aspects of the R&D process easier. However, success in achieving the MDGs will require genuine and effective partnerships between researchers and development practitioners, between public- and private-sector investors, and between researchers in both developed and developing countries. This report gives a flavour of some of the issues, and the progress towards solutions, that will, it is hoped, catalyse the formation of innovative partnerships.

Specific conclusions

The following sections attempt to build on the issues highlighted in this report by identifying trends and opportunities that might be of most interest to the different stakeholders in the global partnership.

Decision-makers, who invest in R&D for agricultural development, including intergovernmental agencies

Section 2 highlighted a few of the recent successes of publicly funded science for agricultural development, for example:

- The development and dissemination of CMV-resistant cassava varieties in Uganda has resulted in an average yield increase of 10 tonnes per ha and estimated benefits of US$ 140 million from an investment of US$ 5 million
- A recent review of the value of the overall impact of the CGIAR system found that the US$ 7 billion invested in the CGIAR between 1960 and 2001 will result in US$ 123 billion of benefits by 2011 (all calculated in terms of 1990 US dollars)

A healthy crop of cassava

Photo: J.Esser

Quantification of impact is possible, but there is room for improvement in methodology

Section 3 showed how research on genomics could help:

- Improve rice, thereby helping the 3 billion people who depend on rice as the mainstay of their diet and the 2 billion small-scale farmers and their families who rely on it for their livelihood
- Protect the 25 million cattle in 11 African countries that are at risk from ECF.

Furthermore, integrated approaches – involving farmers, fisherfolk, researchers and communication specialists, have helped:

- Increase the income of small-scale farmers in Peru by US$ 236 per ha, by combating blight, and US$ 154 per ha, by combating weevils
- Benefit 25,000 fishing families who have learned about good practices in activities such as stock management and conservation.

Investment in new technologies can make a significant contribution to feeding poor people, but partnership approaches add value to the potential impact

The challenge of living in a world affected by climate change and globalization (Section 4) can be daunting, but the emergence of nanotechnology and continuing advances in ICTs will help science keep pace with the changes. The central issue is that discussions about the potential risks of new technologies need to start early to ensure that possible downsides are avoided.

The analysis of investment trends in Section 5 illustrated one of the complexities of living in an interconnected world: how decreasing R&D funding for agriculture in developed countries may decrease the rate of spillover of new science and technology applicable to developing countries.

The public-sector research community

The public-sector research community is a truly global one. It is the engine room of science for agricultural development, yet it is a very diverse community. Some members are familiar with the MDGs, others perhaps will be coming across them for the first time. The exciting aspect of science today is that so much of it can make a genuine contribution to development. Section 2 touched on the range of disciplines required to ensure that research results in positive impact, and this theme was developed in Section 3. Specifically:

- Communication specialists and social scientists joined with natural scientists to ensure that research on potato blight was appropriate for farmers' needs
- Social scientists, with experience in analysing institutional issues and their relationship to policy, contributed to improvements in fisheries management in Bangladesh.

The critical message is that scientists from a wide range of disciplines can, and indeed are needed to, contribute to turning research into impact.

Also in Section 3, the report has highlighted how research on genomics has:

- Benefited many research groups by providing the sequence of the rice genome along with useful methodologies such as sequence-assisted breeding methods associated with SNPs
- Shown how a public–private partnership can be created which cuts across organizations to deliver veterinary products.

You don't need to be living in a developing country to contribute to meeting the MDGs – you can become involved in an innovative partnership

At the same time, the report highlighted (Section 4):

- The growth of regional initiatives in developing countries
- The strengthening of NARSs in Brazil, China and India
- The emergence of new initiatives such as BecA and the AATF, which will enable African scientists to participate in cutting-edge science as part of global partnerships

The central message here is that you don't need to live in a developed country to participate in cutting-edge science. In some developing countries, investment in training and infrastructure is providing new world-class facilities.

By identifying R&D priorities, the CGIAR provides a framework within which partnerships can be built. The priorities are not meant to be exclusive, but rather to draw together groups of scientists committed to development to work in partnership to deliver impact.

Finally, science for agricultural development can only be effective if scientists actively participate in the policy debate leading to investment decisions. The noted forest geneticist, Namkoong (1991) warned: "By hesitating to enter the debate, we only accede the field to the biologically naive and find ourselves able to serve only as peripherally significant technicians in pursuit of the objectives of the uninformed."

The private sector associated with agricultural development

One of the down sides to advances in ICTs is that the public has access to information that is often one-sided and which can lead people to make unduly large estimations of risks. The growing of genetically modified crops could be considered a case in point, as it has resulted in societal suspicion of the private sector. However, in Section 3 this report illustrates how the involvement of the private sector has added value.

- Sequencing of the rice genome was helped by Monsanto and Syngenta. The results of the International Rice Genome Sequencing project could benefit 2 billion small-scale farmers
- The French biotech company Merial is working with university researchers to produce candidate vaccines and novel delivery systems to treat ECF, which causes losses of around £300 million per year.

Researchers are increasingly aware of the potential benefits of working with the private sector and of the IPR issues involved

There are many lessons to be learned from the experiences of crop biotechnology, some of which relate to identifying opportunities for the public good. Section 3 listed some of the potential applications of nanotechnology which could contribute to meeting the MDGs.

Scientist reading a DNA print-out in a biotechnology laboratory

Photo: M.Rose/Panos Pictures

Throughout this report there has been an emphasis on the importance of partnerships and examples of roles that the private sector can play, for example:

- The BecA and AATF initiatives outlined in Section 4
- Emerging opportunities for links with the private sector as part of the new CGIAR priority for vegetables and higher-value crops.

There are many partnership opportunities for the private sector that can contribute towards the global good. These could be with organizations such as the CGIAR or with the emerging regional partnerships led by developing countries.

Development practitioners

In some organizations, the distinction between researchers and development practitioners is blurred. Insufficient funding for research has required researchers to take on a dual role. Such individuals are important in facilitating the exchange of knowledge, but care needs to be taken to ensure that funding for research is used for genuine research, while alternative funding is used to support development. This report is primarily about research but it recognizes that the impacts reported in Section 2 would not have been delivered without development practitioners. Examples include:

Weighing vegetables

Photo: A.Graffham

- Export vegetable production in Kenya is the fastest growing agricultural sub-sector. In 2003 it contributed almost 13% of GDP and is benefiting 50,000 small-scale farmers as well as hundreds of thousands of semi-skilled and unskilled Kenyans – predominantly young females with children, who would struggle to find alternative employment;
- Development and dissemination of CMV-resistant cassava varieties in Uganda has resulted in an average yield increase of 10 tonnes per ha.

Developmental impact can be greatly enhanced by research outcomes

Section 3 highlights the potential benefits expected to result from basic research to sequence organisms' genomes:

- For rice, the genome has been sequenced after 7 years of work, but this will now speed up the delivery of improved rice strains
- Sequencing the genome of *Theileria* is helping vaccine makers to develop new vaccines, but in order to reach the poor, the mode of delivery is important

Development practitioners have an important role to play in identifying and communicating to researchers which characteristics of crops or appropriate delivery mechanisms for vaccines will bring particular benefit to the poor.

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Acronyms and abbreviations

AARINENA	Association of Agricultural Research Institutes in the Near East and North Africa
AATF	African Agricultural Technology Foundation
APAARI	Asia–Pacific Association of Agricultural Research Institutions
ASTI	Agricultural Science and Technology Indicators (CGIAR)
BARI	Bangladesh Agricultural Research Institute
BecA	Biosciences eastern and central Africa
BIOS	Biological Innovation for an Open Society
CAC	Central Asia and the Caucasus
CAMBIA	Center for the Application of Molecular Biology to International Agriculture
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CMV	Cassava mosaic virus
CPHP	Crop Post-Harvest Programme (DFID)
DFID	Department for International Development (UK)
DoF	Department of Fisheries (Bangladesh)
ECF	East Coast Fever
FAO	Food and Agriculture Organization of the United Nations
FARA	Forum for Agricultural Research in Africa
FORAGRO	Forum for the Americas on Agricultural Research and Technology Development
GDP	Gross domestic product
GFAR	Global Forum for Agricultural Research
GPS	Global positioning system
ICT	Information and communication technology
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IP	Intellectual property
IPM	Integrated pest management
IPR	Intellectual property right
IRRI	International Rice Research Institute
KARI	Kenya Agricultural Research Institute
LAC	Latin America and Caribbean
MDG	Millennium Development Goal
NARI	National agricultural research institute

NARO	National agricultural research organization
NARS	National agricultural research system
NEPAD	New Partnership for Africa's Development
NERICA	New rice for Africa
NGO	Non-governmental organization
ODA	Official development assistance
OECD	Organisation for Economic Cooperation and Development
PIPRA	Public Intellectual Property Resource for Agriculture
PPP	Purchasing power parity
R&D	Research and development
RO	Regional organization
SNP	Single nucleotide polymorphism
SRO	Sub-regional organization
SSA	Sub-Saharan Africa
UAE–AGRICENT	United Arab Emirates Agricultural Information Centre
UN	United Nations
US	United States of America
USAID	United States Agency for International Development
WAICENT	World Agricultural Information Centre (FAO)
WHO	World Health Organization
WTO	World Trade Organization

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