

Innovating through science and technology

chapter 7

The technological challenges facing agriculture in the 21st century are probably even more daunting than those in recent decades. With the increasing scarcity of land and water, productivity gains will be the main source of growth in agriculture and the primary means to satisfy increased demand for food and agricultural products. With globalization and new supply chains, farmers and countries need to continually innovate to respond to changing market demands and stay competitive. With climate change, they will have to gradually adapt. All regions, especially the heterogeneous and risky rainfed systems of Sub-Saharan Africa, need sustainable technologies that increase the productivity, stability, and resilience of production systems.¹ These changes imply that technology for development must go well beyond just raising yields to saving water and energy, reducing risk, improving product quality, protecting the environment, and tailoring to gender differences.

Science is also changing rapidly. Revolutionary advances in the biological and information sciences have the potential to enhance the competitiveness of market-oriented smallholders and overcome drought and disease in production systems important to the poor. Consider the win-win of transgenic insect-resistant cotton: it has reduced yield losses, increased farmer profits, and greatly reduced pesticide use for millions of smallholders. But the benefits of biotechnology, driven by large, private multinationals interested in commercial agriculture, have yet to be safely harnessed for the needs of the poor.

The institutional setting for technological innovation is changing rapidly as well—it is more complex, involving plural systems and multiple sources of innovation. The

new world of agriculture is opening space for a wider range of actors in innovation, including farmers, the private sector, and civil society organizations. Linking technological progress with institutional innovations and markets to engage this diverse set of actors is at the heart of future productivity growth.

These changes focus attention on wider innovation systems. With the development of markets, innovation becomes less driven by science (supply side) and more by markets (demand side). New demand-driven approaches stress the power of users—men and women farmers, consumers, and interests outside of agriculture—in setting the research agenda and the importance of research in a value chain from “farm to plate.” Innovation for the new agriculture requires feedback, learning, and collective action among this much broader set of actors.

This chapter looks at the recent record of science and technological innovation from three perspectives:

- The recent impacts and emerging challenges of biological and management technologies
- The investments in research and development (R&D) to generate new technologies, paying particular attention to growing divides between industrial and developing countries, and within the developing countries themselves
- The emerging institutional arrangements that make investments in innovation, including extension, more efficient and effective in meeting market demands through collective action and farmer involvement

The main conclusion: Investments in agricultural R&D have turned much

of developing-world agriculture into a dynamic sector, with rapid technological innovation accelerating growth and reducing poverty. But global and national market failures continue to induce serious underinvestment in R&D and in related extension systems, especially in the agriculture-based countries of Africa. Increasing public and private investment in R&D and strengthening institutions and partnerships with the private sector, farmers, and civil society organizations are now essential to assess user demand for R&D, increase market responsiveness and competitiveness, and ensure that the poor benefit. These investments and institutional innovations will be even more important in the future, with rapidly changing markets, growing resource scarcity, and greater uncertainty.

Genetic improvement has been enormously successful, but not everywhere

Agriculture is a biological process—so technological innovation in agriculture is different from that in other sectors. The 1950s and 1960s showed that genetic improvement technologies such as crop and animal breeds were often location specific and generally did not travel well from the temperate North to the tropical South. Research since

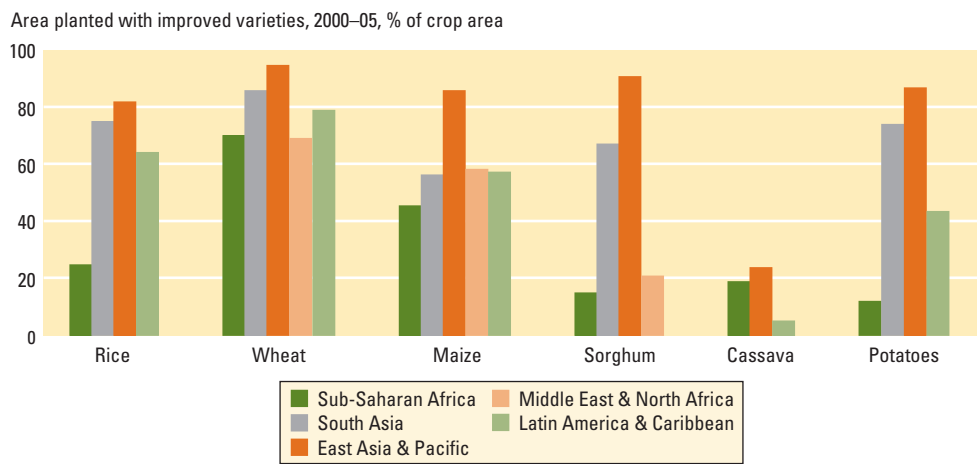
the 1960s aimed at adapting improved varieties and animal breeds to subtropical and tropical conditions has generated high pay-offs and pro-poor impacts. Rapid advances in the biological and informational sciences promise even greater impacts that have yet to be tapped for the benefit of the poor (see focus E).

Slow magic: the continuing spread of improved varieties

Since the 1960s, scientific plant breeding that developed improved varieties suited to smallholders in subtropical and tropical areas—the green revolution—has been one of the major success stories of development (figure 7.1). Initially spearheaded by semidwarf varieties of rice and wheat and improved varieties of maize from international agricultural research centers of the Consultative Group on International Agricultural Research (CGIAR), public breeding programs in developing countries have released more than 8,000 improved crop varieties over the past 40 years.² Private seed companies have also become significant sources of improved hybrid varieties for smallholders for some crops, especially maize.

The contribution of improved crop varieties to yield growth since 1980 has been even greater than in the green revolution

Figure 7.1 Improved varieties have been widely adopted, except in Sub-Saharan Africa



Sources: WDR 2008 team, based on Evenson 2003; <http://www.faostat.fao.org>; IRRI, personal communication 2007; CIMMYT, personal communication 2007.
 Notes: Improved varieties of rice and wheat are semidwarf varieties first developed in what became known as the green revolution. Data are provided for the period 2000–05, except for maize in some Sub-Saharan African countries where data are from 1997.

decades. In the 1980s and 1990s, improved varieties are estimated to have accounted for as much as 50 percent of yield growth, compared with 21 percent in the preceding two decades. Poor consumers have been the main beneficiaries. Without those gains in yields, world cereal prices would have been 18–21 percent higher in 2000, caloric availability per capita in developing countries would have been 4–7 percent lower, 13–15 million more children would have been classified as malnourished, and many more hectares of forest and other fragile ecosystems would have been brought under cultivation.³

Steady genetic improvements to newer generations of varieties—and their spread beyond irrigated areas and rainfed areas with good water control—have contributed to continuing yield gains. For example, improved varieties are now planted on 80 percent of the cereal area in India, only about half of it irrigated.⁴ Newer generations of improved wheat varieties have provided an annual increase in yields of 1 percent, and globally the area planted with them has more than doubled since 1981, largely in rainfed areas.⁵

Not all farmers have been touched by this “slow magic.”⁶ Sub-Saharan Africa has seen very incomplete adoption, with many countries having almost no area under improved varieties. Why the limited green revolution in Sub-Saharan Africa?⁷ The broader mix of crops grown in the region; the agroecological complexities and heterogeneity of the region; the lack of infrastructure, markets, and supporting institutions; and the gender differences in labor responsibility and access to assets all have contributed (chapter 2).⁸

Recent experience in Sub-Saharan Africa offers more promise. After a late start, improved varieties are finally making an impact on some food staples:

- *Maize.* Improved maize varieties and hybrids were widely adopted by smallholders in many African countries in the 1980s, reaching almost universal coverage in a few countries, such as Zimbabwe. But much of this was underwritten by heavy subsidies for inputs and prices, subsidies that were unsustainable.⁹ Still, a substan-

tial share of the maize area was planted to improved varieties and hybrids in 2006 in Kenya (80 percent), Malawi (30 percent), Tanzania (28 percent), Zambia (49 percent), and Zimbabwe (73 percent).¹⁰

- *Cassava.* Improved disease-resistant strains of cassava have been adopted, reaching more than half the cassava area in Nigeria, the world’s largest producer. Cassava has been the fastest growing food staple in Africa, and since it is a staple of the poor, the impacts of productivity gains are especially pro-poor.¹¹
- *Rice.* The New Rice for Africa—combining the high-yielding potential of Asian rice with the resistance of African rice to weeds, pests, diseases, and water stress—was released to farmers in 1996. Increasing yields under low input conditions, it is cultivated on about 200,000 hectares in Africa.¹² Yet adoption is still modest because of insufficient dissemination, training, and extension.
- *Beans.* In eastern, central, and southern Africa, nearly 10 million farmers, mostly women, are reportedly growing and consuming new bean varieties (*Phaseolus vulgaris*), many with multiple stress resistances.¹³

A complementary institutional development in low and uncertain rainfall regions of marginal production potential is participatory varietal selection and breeding approaches that involve farmers in the early stages of plant breeding. Decentralized and participatory approaches allow farmers to select and adapt technologies to local soil and rainfall patterns and to social and economic conditions, using indigenous knowledge as well. Between 1997 and 2004, the Barley Research Program of the International Center for Agricultural Research in Dry Areas in Syria transformed its operation from 8,000 plots planted and evaluated on the research station to 8,000 plots planted in farmers’ fields and evaluated by farmers.¹⁴ It was found that participatory plant breeding and varietal selection speeds varietal development and dissemination to 5–7 years, half the 10–15 years in a conventional plant-breeding program.¹⁵

In the very poor, rainfed rice-growing areas of South Asia that the green revolution passed by, participatory plant breeding is now paying off with strong early adoption of farmer-selected varieties that provide 40 percent higher yields in farmers' fields.¹⁶ The approach needs to be more widely tested in the heterogeneous rainfed environments of Africa, where involving farmers, especially women farmers, in selecting varieties has shown early successes for beans, maize, and rice.¹⁷ The cost effectiveness of the approach for wider use also needs to be evaluated.

But improved varieties alone will not produce a green revolution in less-favored areas; low soil fertility and lack of water control are major constraints that are difficult to overcome through genetic enhancement alone. In the language of crop scientists, both the G (genotype) and the E (crop environment and management) have to change to exploit the type of positive G × E interactions that characterize a green revolution.

Yield risk and the Red Queen

Yield stability is important for all farmers, but especially for subsistence-oriented farmers whose food security and livelihood are vulnerable to pest and disease outbreaks, droughts, and other stresses. Improved varieties can make yields more stable. A recent study concluded that the variability of cereal yields, measured by the coefficient of variation around trends over the past 40 years, has declined in developing countries, a decline that is statistically associated with the spread of improved varieties, even after controlling for more irrigation and other inputs.¹⁸ The annual benefits from better yield stability in maize and wheat alone are estimated at about \$300 million—more than the annual spending on maize- and wheat-breeding research in the developing world.

Yield stability of improved varieties largely reflects long-standing efforts in breeding for disease and pest resistance. Even when improved varieties are bred to resist a disease, they must be periodically replaced to ensure against outbreaks from new races of pathogens. Without investment in such “maintenance research,” yields

would decline—a situation best described by the Red Queen in Alice in Wonderland: “Now here, you see, it takes all the running you can do to keep in the same place.”¹⁹ A third to a half of current R&D investments in crop breeding may be for maintenance, leaving reduced resources to address productivity advances.²⁰

Underinvesting in maintenance research can threaten local food supplies and sometimes have global significance. Consider the dramatic recent emergence of Ug99, a new race of stem rust (*Puccinia graminis tritici*) in wheat, the world's second most important food staple. Stem rust is catastrophic because it can cause an almost complete loss of crops over wide areas. Ug99 first appeared in 1999 in Uganda and is now widespread in wheat-growing areas of Kenya and Ethiopia; in 2007 it was found in Yemen. Based on previous experience, Ug99 is expected to be carried by the wind through the Middle East to wheat-growing areas of South Asia and possibly to Europe and the Americas. Given the narrow base of genetic resistance to the disease in existing varieties of wheat, the spread of Ug99 could cause devastating losses in some of the world's breadbaskets.²¹ The last major outbreak of stem rust in the United States in 1953 and 1954 caused a 40 percent yield loss worth \$3 billion in today's dollars.²² Through a new international effort, plant breeders and pathologists should be able to avoid a global epidemic by screening for resistant genotypes and getting them into farmers' fields.

Farmers who use traditional varieties are also vulnerable to random outbreaks of disease, as with the recent outbreak of bacterial wilt (Banana *Xanthomonas* wilt) in East Africa. The disease threatens the livelihoods and food security of millions of people who depend on bananas in the Great Lakes Region—an area that boasts the world's highest per capita consumption of bananas.²³ In Uganda, where bananas are a staple, the potential national loss is estimated at \$360 million a year.²⁴ A genetically engineered variety with resistance to the disease is a breakthrough, but applying it depends on Uganda's putting biosafety regulations in place (see focus E).²⁵

These recurring crises are wake-up calls to develop appropriate maintenance research strategies together with global coordination, surveillance, and financing.

Progress in developing varieties that perform well under drought, heat, flood and salinity has been generally slower than for disease and pest resistance. The International Maize and Wheat Improvement Center (CIMMYT), after more than 30 years of research to produce drought-tolerant maize varieties and hybrids, is now seeing results in eastern and southern Africa. Evaluated against existing hybrids, the new ones yield 20 percent more on average under drought conditions.²⁶ Similarly, recent evidence points to significant yield gains in breeding wheat for drought and heat-stressed environments.²⁷ New varieties of rice that survive flooding have also been identified.²⁸ Such advances in drought, heat, and flood tolerance will be especially important in adapting to climate change.

But large areas of major food crops are now planted each year in relatively few improved varieties, and genetic uniformity can make crops vulnerable to major yield losses. There is some evidence that genetic uniformity increases yield risk, even though it can also produce higher yields.²⁹ In recent decades, the world has largely avoided major disasters from genetic uniformity, in part because of frequent turnover of varieties, which brings new sources of resistance. Even so, wider conservation and use of genetic resources are needed (chapter 11).

Beyond crops: genetic improvement of livestock and fish

Advances in animal and fish genetics combined with improved animal health and feeding have been the basis of the livestock revolution in developing countries (chapter 2). Improved pig and poultry breeds have been adopted through private direct transfers from the North.³⁰ These gains show up in livestock productivity. Over 1980–2005 in the developing world, the annual off-take from a flock of chickens with a total live weight of 1,000 kilograms increased from 1,290 kilograms to 1,990 kilograms and that of pigs improved from 140 kilograms to 330 kilograms live weight.³¹

The cross-breeding of dairy cows with exotic breeds has improved the livelihoods of smallholder farmers in high-potential areas in the tropics. About 100 million cattle and pigs are bred annually in the developing world using artificial insemination.³² And thanks largely to artificial insemination, about 1.8 million small-scale farmers in the highlands of East Africa draw a significant part of their livelihood from the higher milk yields they obtain from genetically improved dairy cattle.³³

Similarly for fish, genetically improved tilapia is changing aquaculture into one of the fastest growing sectors in Asian agriculture. In 2003 improved strains from a single project—for the genetic improvement of farmed tilapia (GIFT)—accounted for 68 percent of the total tilapia seed produced in the Philippines, 46 percent in Thailand, and 17 percent in Vietnam. Lower production costs per kilogram of fish, high survival rates, higher average weight per fish, and yields 9–54 percent higher than existing strains explain the fast uptake of GIFT-derived strains.³⁴

Even so, genetic improvement in animals and fish have reached only a small share of developing-country farmers, partly because of constraints in the delivery systems for these technologies. Livestock breeding services in much of the developing world are still generally subsidized, crowding out the private sector. More research to reduce the costs of these technologies, and more policy and institutional reforms to ensure more efficient and widespread delivery, will enable the developing world to capture the full benefits of these promising technologies.

A biotechnology revolution in the making?

Agricultural biotechnology has the potential for huge impacts on many facets of agriculture—crop and animal productivity, yield stability, environmental sustainability, and consumer traits important to the poor. The first-generation biotechnologies include plant tissue culture for micro-propagation and production of virus-free planting materials, molecular diagnostics of crop and livestock diseases, and embryo transfer in livestock. Fairly cheap and eas-

ily applied, these technologies have already been adopted in many developing countries. For instance, disease-free sweet potatoes based on tissue culture have been adopted on 500,000 hectares in Shandong Province in China, with yield increases of 30–40 percent,³⁵ and advanced biotechnology-based diagnostic tests helped eradicate rinderpest virus in cattle.

The second-generation biotechnologies based on molecular biology use genomics to provide information on genes important for a particular trait. This allows the development of molecular markers to help select improved lines in conventional breeding (called marker-assisted selection). Such markers are “speeding the breeding,” leading to downy mildew-resistant millet in India; cattle with tolerance to African sleeping sickness; and bacterial leaf blight-resistant rice in the Philippines.³⁶ As the costs of marker-assisted selection continues to fall, it is likely to become a standard part of the plant breeder’s toolkit, substantially improving the efficiency of conventional breeding.

The most controversial of the improved biotechnologies are the transgenics, or genetically modified organisms, commonly known as GMOs (see focus E). Transgenic technology is a tool for “precision breeding,” transferring a gene or set of genes conveying specific traits within or across species. About 9 million smallholder farmers, mainly in China and India, have adopted transgenic Bt cotton for insect resistance. It has already reduced yield losses from insects, increased farmer’s profits, and significantly reduced pesticide use in India and China. Transgenic technology remains controversial, however, because of perceived and potential environmental and health risks.

Biotechnology thus has great promise, but current investments are concentrated largely in the private sector, driven by commercial interests, and not focused on the needs of the poor. That is why it is urgent to increase *public* investments in pro-poor traits and crops at international and national levels—and to improve the capacity to evaluate the risks and regulate these technologies in ways that are cost effective

and inspire public confidence in them. The potential benefits of these technologies for the poor will be missed unless the international development community sharply increases its support to interested countries (see focus E).

Management and systems technologies need to complement genetic improvement

Much R&D is focused on improving the management of crop, livestock, and natural resource systems. The CGIAR invests about 35 percent of its resources in sustainable production systems, twice the 18 percent it invests in genetic improvement.³⁷ Much of this work has emphasized soil and water management and agroecological approaches that exploit biological and ecological processes to reduce the use of non-renewable inputs, especially agricultural chemicals.³⁸ Examples include conservation tillage, improved fallows and soils, green manure cover crops, soil conservation, and pest control using biodiversity and biological control more than pesticides.

Zero tillage

One of the most dramatic technological revolutions in crop management is conservation (or zero) tillage, which minimizes or eliminates tillage and maintains crop residues as ground cover. It has many advantages over conventional tillage: increasing profitability from savings in labor and energy, conserving soil, increasing tolerance to drought, and reducing greenhouse gas emissions. But it makes the control of weeds, pests, and diseases more complex, and it usually requires some use of herbicides.

In Latin America (mainly Argentina and Brazil), zero tillage is used on more than 40 million hectares (about 43 percent of the arable land).³⁹ Originally adopted by large and midsize farmers, the practice has spread to small farmers in southern Brazil. Networks of researchers, input suppliers, chemical companies, and farmers have used participatory research and formal and informal interactions to integrate various parts of the technology (rotations, seeds,

BOX 7.1 *When zero means plenty: the benefits of zero tillage in South Asia's rice-wheat systems*

South Asia's rice-wheat systems, the bedrocks of food security, are in trouble (chapter 8). Long-term experiments show that crop yields are stagnating and that soil and water quality are in decline. In response, the Rice-Wheat Consortium of the Indo-Gangetic Plain of South Asia—a network of international scientists, national scientists, extension agents, private machinery manufacturers, and nongovernmental organizations (NGOs)—has developed and promoted zero-tillage farming.

Although zero tillage is part of a much broader farm management system that involves many agricultural practices, a key part of the system promoted by the consortium is planting wheat immediately after rice without tillage so that the wheat seedlings germinate using the residual moisture from the previous rice crop. A notable aspect of the approach has been to work with local machinery manufacturers and farmers to adapt drills to local conditions.

Zero-tillage farming increases wheat yields through timely sowing and reduces

production costs by up to 10 percent. It reduces water use by about 1 million liters per hectare (a saving of 20–35 percent). It improves soil structure, fertility, and biological properties and reduces the incidence of weeds and some other pests. Zero tillage with wheat succeeding rice is now the most widely adopted resource-conserving technology in the Indo-Gangetic Plain, especially in India with some 0.8 million hectares planted in 2004 using the method. Research on zero tillage on rice-wheat systems in India is estimated to have a rate of return of 57 percent, based on an investment of \$3.5 million.⁴⁰

Further work must consider the fact that women contribute more than half the labor in the rice-wheat system, especially for livestock management. This has important implications for involving women in seed selection and fodder management practices for the system.

Sources: Malik, Yadav, and Singh 2005; Paris 2003.

chemicals, and machinery) and adapt them to local conditions. The approach was also used by an estimated 100,000 smallholders in Ghana in the past decade.⁴¹ It is also being rapidly adopted in the irrigated wheat-rice systems of the Indo-Gangetic Plain (box 7.1).

Legumes and soil fertility

Another input-saving and resource-conserving technology is introducing or improving legumes in farming systems to provide multiple benefits, most notably biologically fixing nitrogen that reduces the need for chemical fertilizer (especially if the legume is inoculated with nitrogen-fixing *Rhizobium*). Much of the yield gain in Australian cereal production over the past 60 years comes from rotation systems that include legumes.⁴² In southern Africa, fast-growing “fertilizer” trees such as *Gliricidia*, *Sesbania*, and *Tephrosia* have improved soil fertility, soil organic matter, water infiltration, and holding capacity. Other benefits include reduced soil erosion and the production of fuelwood and live-

stock fodder (box 7.2).⁴³ These technologies are quite location specific, however, and research to adapt them to farming systems defined by soils, land pressure, and labor availability (differentiated by men and women) should be a high priority to address the severe depletion of soil nutrients in Sub-Saharan Africa.

Pest management

At the other end of the spectrum, research that reduces use of dangerous pesticides can have win-win-win benefits for profitability, the environment, and human health in intensive systems. Integrated pest management uses a combination of practices, especially improved information on pest populations and predators to estimate pest losses and adjust pesticide doses accordingly. Despite notable examples of integrated pest management, adoption has often been limited because of its complexity (chapter 8).

However, biological control of pests can sometimes have spectacular impacts, often requiring no action on the part of farmers. One of the best-documented cases is the control of the cassava mealybug in Sub-Saharan Africa, which was introduced accidentally with planting material from Latin America in the 1970s, causing significant economic losses.⁴⁴ The International Institute for Tropical Agriculture responded to the crisis by selecting, rearing, and distributing in 20 countries a parasitoid wasp that was the mealybug's natural enemy. The biological control provided by the wasp was so effective that the cassava mealybug is now largely controlled. Even when using the most conservative assumptions, the return on this research investment has been extremely high (net present value estimated at US\$9 billion).⁴⁵

Combinations

The greatest impact on productivity is obtained through production ecology approaches that combine improved varieties and several management technologies, crop-livestock integration, and mechanical technologies to exploit their synergistic effects.⁴⁶ For example, in Ghana zero tillage is combined with improved legume-based

fallows and maize varieties.⁴⁷ In eastern Africa, low-input integrated pest management has been developed by planting *Desmodium* (a nitrogen-fixing leguminous plant that can be used for livestock fodder) between the rows of maize to suppress *Striga*, an especially serious parasitic weed.⁴⁸ A similar integrated approach involving improved varieties, biological nitrogen fixation, cover crops, and machinery adapted to zero tillage has been vital to the global competitiveness of Brazilian soybeans.⁴⁹ With the rise of value chains, such technologies must also often integrate product quality and agricultural processing.

The need for more suitable technologies

Although R&D on production and resource management has huge potential, success has been mixed, with zero tillage as the outstanding success. Suitable technologies are still badly needed to conserve and efficiently use scarce water, control erosion, and restore soil fertility for smallholders in less-favored areas. However, such complex technologies are often labor or land intensive and may be unattractive to farmers where labor costs are high, land is scarce, or discount rates on future returns are very high or the returns risky. These concerns are especially important to women farmers lacking access to assets and services and who have specific seasonal labor-use patterns. Although the technologies are aimed at poor farmers, the record shows higher adoption levels by wealthier farmers.⁵⁰

Management and systems technologies can require considerable institutional support to be widely adopted (chapter 8). Many of them involve the interaction of several actors—such as collective action among neighboring farmers—as well as technical support, learning, farmer-to-farmer interaction, and knowledge sharing, as with conservation tillage in Brazil. In addition, many technologies have positive impacts on the environment that are not captured in the private benefits for adopting farmers and may require payment for environmental services to encourage their adoption (chapter 8).

BOX 7.2 *Using legumes to improve soil fertility*

The low fertility in much of African soil and the low (and sometimes declining) use of mineral fertilizers have increased farmer interest in agroforestry-based soil fertility systems. The main methods are a rotational fallow or a permanent intercrop of nitrogen-fixing trees. The systems have spread mainly in the southern African subhumid region, where they have more than doubled maize yields and increased net returns on land and labor. In Zambia, the financial benefits to the nearly 80,000 farmers practicing improved fallows were

almost \$2 million for 2005/06. The technologies often work best in combination with judicious doses of mineral fertilizer.

With 12 million smallholder maize farmers in eastern and southern Africa, rotational fallows and permanent intercropping offer considerable long-term opportunities for integrated soil fertility management to keep African soils productive and healthy.

Source: Consultative Group on International Agricultural Research Science Council (CGIAR) 2006a.

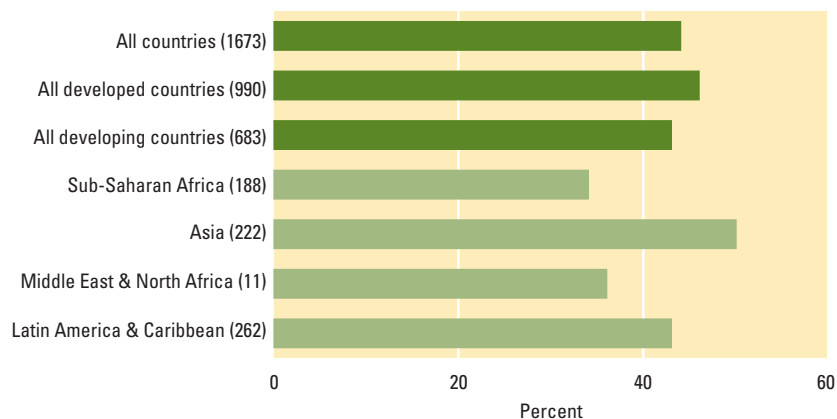
The integrative nature of management and agroecological approaches also affects the way R&D is carried out. Because of location specificity, farmer and community participation in R&D characterizes the major success stories of these technologies. Location specificity also reduces the potential for spillovers of technologies from other regions—so despite substantial investment by the CGIAR, the evidence of impacts is limited.⁵¹

For these reasons, scaling up management and system technologies will not be easy. Networks of scientists, farmers, private firms, and NGOs take time to develop and become inclusive and effective. They also take time to develop the “ecological literacy” to successfully apply many of these technologies (chapter 8). But advances in geographic information systems and remote sensing by satellites are opening new ways to synthesize complex and diverse spatial data sets, creating new opportunities for collaboration among scientists, policy makers, and farmers.

Investing more in R&D

Agricultural productivity improvements have been closely linked to investments in agricultural R&D (chapter 2).⁵² Published estimates of nearly 700 rates of return on R&D and extension investments in the developing world average 43 percent a year.⁵³ Returns are high in all regions, including Sub-Saharan Africa (figure 7.2). Even discounting for selection bias in evaluation studies and other methodological

Figure 7.2 Estimated returns to investment in agricultural R&D are high in all regions^a—averaging 43 percent



Source: Alston and others 2000.

a. Based on studies carried out from 1953 to 1997. Number of observations in parentheses.

issues,⁵⁴ there is little doubt that investing in R&D can be a resounding success. The high payoffs relative to the cost of capital also indicate that agricultural science is grossly underfunded.

Why agricultural R&D is underfunded

Public investment is especially important for funding agricultural R&D where markets fail because of the difficulty of appropriating the benefits. Seeds of many improved varieties can be reused by farmers and sold or shared with neighboring farmers (nonexcludable). Information on improved management practices can be freely exchanged (nonrival). Intellectual property rights (IPRs) have partially overcome these market failures in industrial countries, but few technologies of importance to poor farmers can be cost-effectively protected by IPRs (box 7.3). A major exception is private sector investment in hybrid seed of a few crops where intellectual property can be protected by trade secrets. Farmers must purchase hybrid seed frequently to maintain its yield advantage, providing a steady market for private seed companies.

Star performers—and the others. For these reasons, private investment in developing-country R&D has been very limited—94 percent of the agricultural R&D in the developing world is conducted by the

public sector.⁵⁵ But even growth in public spending on R&D, after rapidly increasing in the 1960s and 1970s, has slowed sharply in most regions in the past decade or more, opening a knowledge divide between poor countries and rich countries and within the developing world between a handful of “star performers” and most of the others.

Developing countries as a group invested 0.56 percent of their agricultural gross domestic product (GDP) in agricultural R&D in 2000 (including donor contributions), only about one-ninth of the 5.16 percent that developed countries invest. Part of this disparity is because private investment makes up just over half of R&D spending in industrial countries but only 6 percent in the developing world. Still, the intensity of public investment (in relation to agricultural GDP) is five times higher in industrial countries (table 7.1).

A few developing countries—notably China, India, and to a less extent, Brazil—have rapidly increased their spending on agricultural R&D over the past two decades. Their shares in developing-country public spending in agricultural R&D increased from a third in 1981 to almost half in 2000. Including spending on science and technology for all sectors, these three countries accounted for 63 percent of the total—which is meaningful, because an increasing share of agricultural R&D is carried out in general science and technology organizations.⁵⁶ The private sector also has a growing presence in these countries, where expanding agricultural input markets provide incentives to invest.

Meanwhile, many agriculture-based countries are flagging or slipping in the amount spent on R&D. In the 1990s, public R&D spending in Sub-Saharan Africa fell in nearly half the 27 countries with data, and the share of agricultural GDP invested in R&D fell on average for the whole region.⁵⁷

Politics, prices, and spillovers. Why does this underinvestment in R&D continue, given the well-documented high rate of return on investment? Three main reasons: First, the political economy of public expenditure decisions tends to emphasize short-term payoffs and subsidies that are

BOX 7.3 *Stronger IPRs in developing countries: effect on small farmers*

Under the World Trade Organization (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights, member countries are required to implement IPRs, including those for plant varieties and biotechnology inventions. The most common type of protection is through plant variety rights. A handful of developing countries also provide patent protection.

Many developing countries have elected to follow the model developed in 1978 by industrial countries, the Convention on the Protection of New Varieties of Plants—known by its implementing agency, the International Union for the Protection of New Varieties of Plants (UPOV), which harmonized conditions and norms for protecting new varieties while giving farmers the right to save and exchange seed. Other countries (for example, India and Thailand) explicitly recognize framework farmers’ rights to save and exchange seed (derived from the 2004 international treaty of the Food and Agriculture Organization of the UN [FAO]) and to share benefits arising from the use of farmers’ genetic resources and indigenous knowledge (based on the 1993 Convention on Biological Diversity).

North-South bilateral and regional trade agreements often put pressure on developing countries to adopt even stronger protection—such as that based on the 1991 Convention of UPOV, which makes selling and exchanging seed of protected varieties illegal.

Little impact so far

A recent review of the impacts of stronger IPRs on the seed industries of China, Colombia, India, Kenya, and Uganda found relatively little impact to date, mainly because the IPRs are still under development in most countries. Although limitations on the exchange of farmer-saved seed appear a significant obstacle to smallholder farmers, there are no indications that such rules have been enforced. Indeed, it is generally not cost effective to enforce such rules for staple crops grown by smallholders. Also, the potential advantages of IPRs should not be overrated in most developing countries. Relative to broader investment climate issues, IPRs do not seem critical in the initial development of a private seed sector, but they could help to support a maturing commercial seed industry.

How countries could do more

Even so, countries could do more to adapt IPR legislation to their needs within the guidelines of current international treaties. For example, a country could provide strong protection for commercial crops as an incentive for private investment, while excluding or providing weaker protection to staple food crops important to subsistence-oriented farmers, where seed saving and exchange are integral to farming practices.

Only a few developing countries with large commercial sectors or potential in private biotechnology R&D should consider strong IPRs, such as UPOV 1991 and strong patent laws. Plant variety rights also need to fit into other regulatory systems, such as seed certification laws, biosafety laws, and such other IPRs as trademarks and trade secrets. In any event, sharply increased capacity of the public sector, private firms, and farmers is needed to design and build credible and cost-effective IPR systems that fit a country’s needs.

Sources: Oxfam International 2007b; Tripp, Louwaars, and Eaton 2007; World Bank 2006k.

Table 7.1 Total public agricultural R&D expenditures by region, 1981 and 2000

	Public agricultural R & D spending		R & D spending as a % of agricultural GDP	
	1981	2000	1981	2000
	2000 int’l \$, millions			
Sub-Saharan Africa	1,196	1,461	0.84	0.72
Asia & Pacific	3,047	7,523	0.36	0.41
China	1,049	3,150	0.41	0.40
India	533	1,858	0.18	0.34
West Asia & North Africa	764	1,382	0.61	0.66
Latin America & Caribbean	1,897	2,454	0.88	1.15
Brazil	690	1,020	1.15	1.81
Developing countries	6,904	12,819	0.52	0.53
Japan	1,832	1,658	1.45	3.62
United States	2,533	3,828	1.31	2.65
Developed countries	8,293	10,191	1.41	2.36
Total	15,197	23,010	0.79	0.80

Sources: Agricultural Science and Technology Indicators database, <http://www.asti.cgiar.org>; Pardey and others 2007. Note: These estimates exclude Eastern Europe and the former Soviet Union countries because data are not available.

“politically visible” (chapter 4), while agricultural R&D investments are both long term (10 years or more) and risky. Moreover, in agriculture-based countries, the political power of farmers is low anyhow (chapter 1). Second, trade distortions and national policies that reduce incentives to

farmers in developing countries are a disincentive to both public and private investment in R&D (chapter 4).⁵⁸

Third, because the benefits of much public R&D spill over to other countries, it might not make much economic sense for small countries to spend their scarce

resources on agricultural science, on their own behalf; many nations have been free-riding on the efforts of a few others. The international agricultural research centers of the CGIAR were created specifically to provide spillovers in many areas of technology.⁵⁹ Over half of all benefits of R&D are generated by such spillovers.⁶⁰

But future reliance on spillovers for productivity enhancement carries risks.⁶¹ Privatization of R&D restricts access to proprietary technologies and the sharing of scientific knowledge (see below). Traditional sources of spillovers for productivity growth—the public R&D systems in developed countries and the CGIAR—have also shifted priorities away from productivity-enhancing research to research on the environment and food safety and quality.⁶² In some regions, especially Sub-

Saharan Africa, there is less potential to capture spillovers because of the relative uniqueness of their agroclimatic conditions and crops (box 7.4).

Ways to increase investment in R&D

Increasing public funding of R&D will require greater political support to agriculture, particularly to finance public goods. Forming coalitions of producers and agribusinesses around particular commodities or value chains may be the most effective way to lobby for more public funding and for producers and agribusiness to cofinance R&D. In addition, institutional reforms, discussed next, will be needed to make investing in public R&D organizations more attractive—and more effective.

Another way to increase investment is to remove barriers to private investment

BOX 7.4 Sub-Saharan Africa's agricultural R&D challenge

In addition to stagnant R&D spending, Sub-Saharan Africa faces specific challenges that add urgency to increasing the spending on agricultural R&D, extension, and associated services:

- The potential to capture spillovers of technology from outside the region is less in Sub-Saharan Africa than in other regions. This is partly because the crops grown in Sub-Saharan Africa are more diverse, with many so-called orphan crops where there is little global public or private R&D (for example, cassava, yams, millet, plantain, teff), and partly because of "agroecological distance." Using an index of agroecological distance—zero to represent no potential for spillovers from high-income countries, where most R&D is conducted, and 1 for perfect spillover potential—Pardey and others (2007) estimate that the average index for African countries is 0.05, compared with 0.27 for all developing countries. So, technologies imported from other continents often do not perform well.
- There is considerable heterogeneity within Africa resulting from rainfed production systems, reducing the spillover potential among countries in the region.
- Because of small country size, agricultural research systems in Sub-Saharan Africa are fragmented into nearly 400 distinct research agencies, nearly four times the number in India and eight times that in the United States (table below). This prevents realizing economies of scale in research.
- Funding per scientist is especially low in Sub-Saharan Africa. With nearly 50 percent more scientists than India, and about a third more than the United States, all of Sub-Saharan Africa spends only about half of what India spends and less than a quarter of what the United States spends. Only a quarter of African scientists have a PhD, compared with all or most scientists in India and the United States.
- Complex agricultural challenges in Sub-Saharan Africa require combining genetic improvement emphasizing pests, diseases, and drought, with improvements in soil and water management, and with labor-saving technologies in areas of low population density or serious HIV/AIDS infection.

These problems are surmountable. First, Australia, another dryland continent technologically distant from other regions, has one of the highest intensities of public R&D investment in the world (more than 4 percent of agricultural GDP); it has a productive and competitive agricultural sector. Second, spillovers can be better targeted at a world scale—for example, East African highland countries such as Ethiopia and Kenya have product mixes and agroecological conditions similar to Mexico. Third, the rise of regional research organizations in Africa should help achieve economies of scale and scope.

Comparison of research systems in Sub-Saharan Africa, India, and the United States around 2000

	Sub-Saharan Africa	India	United States
Arable and permanent crop area (hectares, millions)	147	160	175
Number of public agricultural research agencies	390	120	51
Number of full-time equivalent scientists	12,224	8,100	9,368
Percentage of scientists with PhD	25	63	100
Annual public spending on agricultural R&D (1999 int'l \$, millions)	1,085	1,860	3,465
Spending per scientist (1999 int'l \$, thousands)	89	230	370

Sources: FAO 2006a. Pal and Byerlee 2006; Pardey and others 2007.

in R&D. One constraint to private R&D investment is a weak investment climate for private investors generally (see focus D). A second is weak demand from smallholders for improved technologies because of risks, credit constraints, and poor access to information. A third is that production systems and technologies in much of the developing world make it difficult to enforce IPRs. Added to these three are restrictions on private sector imports of technologies and high regulatory barriers to the release of new technologies, such as the varieties developed by the private sector.⁶³

More could be done to stimulate private investment in R&D by improving the environment for private innovation—say, through stronger IPRs for inventions for commercial crops (see box 7.3) and lower barriers to the import and testing of technologies. Another approach is to make public funding for R&D contestable and open to private firms to implement the research, usually with private cofinancing. Competitive funding has become common, especially in Latin America, and some funds have the specific objective of funding private innovation (FONTEC in Chile, for example). Yet another approach is to establish a “purchase fund” or prize to reward developers of specific technologies, such as varieties resistant to a particular disease.⁶⁴ Prizes were used historically to promote inventions, such as an accurate way to measure longitude.⁶⁵ The reward could also be tied to the economic benefits actually generated.⁶⁶

Institutional arrangements to increase the efficiency and effectiveness of R&D systems

Although public research organizations dominate in most developing countries, their efficiency and effectiveness in today’s changing world are in question. Institutional reforms of public R&D were addressed in *World Development Report 2002*. They include creating well-governed autonomous bodies or public corporations, such as EMBRAPA (the Brazilian public agricultural research corporation); improving their effectiveness in assessing and responding to farmer demands;

and increasing the contestability of funding through competitive funding mechanisms. To succeed, these reforms have to be accompanied by a long-term commitment to build capacity (box 7.5), which has paid off in the now-strong public research systems in Brazil, China, and India. A challenge for public research systems in Africa is attracting and retaining scientists, who operate in a global marketplace, especially women scientists—who make up only 21 percent of the total (see focus G).⁶⁷

Research universities are also underused for publicly supported science. Competitive funding mechanisms for public funds have increased the role of universities in agricultural R&D in some countries. For example, 30–50 percent of the competitive grants for agricultural R&D in Brazil, Chile, Ecuador, and Mexico have been channeled to universities.⁶⁸ Moreover, universities prepare the next generation of scientists. A comprehensive agricultural science policy is needed to address continuing weaknesses in university systems, especially in agriculture-based countries (see focus G).

While investment in public R&D organizations remains important, the public sector cannot do it alone. Science-driven and linear research-extension-farmer approaches—in which public research systems generate technologies disseminated

BOX 7.5 Long-term capacity development in Ghana

The Ghana Grains Development Project is one of the few African success stories of long-term donor support to strengthen national research and extension for food production. Ghana is also one of the few countries with sustained increases in per capita food production. The project focused primarily on increasing the output of maize and cowpeas through well-adapted varieties and management practices for each of Ghana’s agroecological zones. A special feature was the graduate-level training of about 50 scientists, nearly all of whom returned to the project.

Annual maize production jumped from 380,000 tons in 1979, when the project started, to more than 1 million tons by the project’s end in 1998. Maize yields increased by 40 percent from 1.1 tons per hectare to 1.5 tons.

The project’s bottom-up approach integrated farmers in all stages of research and included socioeconomic assessment of the technology. Complemented by large-scale extension programs supported by the NGO Sasakawa Global 2000, more than half of all maize farmers in Ghana adopted improved varieties, fertilizer, and planting methods by 1998. But after the removal of fertilizer subsidies, fertilizer use dropped to 25 percent, challenging the approach’s sustainability. Adoption by women farmers (39 percent) was significantly lower than that for men (59 percent), reflecting differences in access to assets and services, and especially the biases in extension.

Sources: Canadian International Development Agency, personal communication, 2006; Morris, Tripp, and Dankyi 1999.

through largely public extension systems to farmers—worked well in some contexts (the green revolution). But they work less well in meeting today's rapidly changing market demands, especially for high-value and value-added products. Nor are they suited to more heterogeneous contexts, as in rainfed areas of Sub-Saharan Africa, where more comprehensive approaches are needed to secure development and adoption of technological innovations.

To improve the efficiency and effectiveness of R&D, collective action and partnerships involving a variety of actors in an innovation systems framework are emerging as important. Such a framework recognizes multiple sources of innovation, and multiple actors as developers and users of technologies, in a two-way (nonlinear) interaction. Such systems have many advantages. They can pool complementary assets such as intellectual property, genetic resources, and research tools. They can reap economies of scale and scope. They can facilitate technology transfers through arrangements with private input distributors. They can promote integrated value chains. And they can foster mechanisms to express consumer and farmer demands for technology and product traits.

Global and regional partnerships for economies of scale

The high fixed costs of much of today's research require economies of scale in R&D. That puts small and medium-size countries and research organizations at a disadvantage for some kinds of research. Many developing countries may be too small to achieve efficient scale in agricultural R&D, except in adaptive research. A challenge for global efficiency in agricultural science, and for many smaller countries, is to develop institutions for financing and organizing research on a multinational basis.⁶⁹

The CGIAR was created to facilitate such spillovers by producing international public goods that benefit the poor. Its collective action, with 64 funders and 15 international centers, has been one of agriculture's global success stories. The CGIAR system is critical for small, agriculture-based countries to underwrite the cost of R&D, but

even industrial countries benefit from it. Its future success depends on increasing its core funding and sharply focusing its priorities (chapter 11).

International cooperation in R&D goes well beyond the CGIAR. Growing capacities in the large countries with dynamic R&D systems, such as Brazil, China, and India, represent an underused resource for South-South cooperation that other developing countries can tap, with modest funding. New collaborative arrangements among developing countries make this possible. FONTAGRO, the Regional Fund for Agricultural Technology for Latin America and the Caribbean, is one example. Created in 1998 as a consortium of 13 countries, FONTAGRO allocates grants competitively to organizations in the region, achieving economies of scale and scope for preestablished research priorities.⁷⁰ Similar approaches are being implemented through the Forum for Agricultural Research in Africa and several subregional associations. The Latin American Fund for Irrigated Rice, which includes members from public and private sectors and from producer organizations in 13 countries, finances regional rice improvement research.

Public-private partnerships

Given the dominance of public systems for R&D in developing countries, and the global role of the private sector in R&D and in value-chain development, public-private partnerships (PPPs) offer much potential and are proliferating.

Making biotech available to smallholders.

One type of PPP makes the products of biotechnology available to smallholders in the developing world, in areas where the private sector has little commercial interest. Biotechnology partnerships can link global and local actors through complex agreements that reflect their assets (table 7.2)—the CGIAR has 14 such partnerships.⁷¹ Some partnerships also reflect the rise of new philanthropists, such as the Gates Foundation and foundations (Syngenta Foundation) associated with private biotechnology companies, that provide both new sources of private funding and access to research tools and technologies.

Table 7.2 Assets of public and private sectors in agribiotechnology research

Institution/firm	Scientific and knowledge assets	Other assets
Multinational research firms (life-science firms)	Genes, gene constructs, tools, related information resources	Access to international markets and marketing networks
	Biotechnology research capacity	Access to international capital markets Economies of market size IPR skills
International agricultural research centers (CGIAR)	Germplasm collections and informational resources	Access to regional/global research networks
	Conventional breeding programs and infrastructure	Access to bilateral/multilateral donor funding
	Applied/adaptive research capacity	Generally strong reputational integrity
National agricultural research institutes in medium-size countries	Local/national knowledge and materials	Seed delivery and dissemination programs and infrastructure
	Conventional breeding programs and infrastructure	Generally strong reputational integrity
	Applied/adaptive research capacity	
Local firms	Local/national knowledge and materials	Seed distribution and marketing infrastructure
	Applied/adaptive research capacity	

Source: Adapted from Byerlee and Fischer (2002) and Spielman and von Grebmer (2004).

Note: For simplicity, advanced research institutes and other players in the global research system are excluded from this table.

Despite the promise, PPPs of this type have been slow to deliver results on the ground because of high transaction costs in negotiating intellectual property agreements (box 7.6); asymmetric information on asset positions and bargaining chips; clashes of public and private cultures; and a lack of mutual trust, resulting in coordination failures across actors.⁷²

Innovating in value chains. A second type of partnership is being stimulated by new markets for high-value products and supply chains. In those chains, innovation may be less dependent on local R&D because the technology for many high-value products is less location-specific than that for traditional staples (for example, horticulture in greenhouses and stall-fed dairy farming). A dynamic system of innovation comprises private business, farmers, processors, regulatory bodies, and public R&D organizations operating in partnerships, networks, or consortia.

Policymakers can facilitate these PPPs by providing incentives for innovation through competitive funds that cofinance both R&D and the pilot testing of innovations, usually in partnership with private actors: farmers, processors, or other agribusinesses. India’s National Agricultural Innovation Project will support about 15 value chains, such as those for biofuels and livestock, at roughly \$5 million apiece, through this approach.

BOX 7.6 *IPR options to give the poor access to modern science*

The increasing share of tools and technologies protected as intellectual property in the developed world—by both the public and private sectors—poses a major challenge to harnessing them for the benefit of poor people.

For many countries, the fact that a gene or tool is protected in rich countries may not be a problem, as IPRs are relevant only in the country awarding the patent or plant variety right (unless a product derived from the gene or tool is exported to a country holding the IPR). Since many small countries and least-developed countries are not attractive commercial markets for private companies, few patents are taken out in those countries. Countries may unilaterally decide to use a particular gene or tool if they can physically obtain it (by obtaining seed with a desired gene).

Patent protection is more common for the rapidly emerging and larger countries. For all countries, timely access to new tools and technologies, as well as the tacit knowledge required to use them effectively, increases the value of a formal agreement to obtain access.

Some innovative approaches to acquire proprietary science—or at least reduce the transaction costs of doing so—for the benefit of small farmers in the developing world include the following:

- *Market segmentation and humanitarian licenses* recognize that many technologies may benefit poor farmers who are not an attractive market for private firms.

Golden Rice with enhanced Vitamin A is an example: patents have been negotiated for humanitarian use for farmers in the developing world with incomes under \$10,000 a year.

- *Public Intellectual Property Resource for Agriculture* is a consortium of public R&D organizations that encourages intellectual property sharing in the public sector and provides licenses for humanitarian use in the developing world.
- *Biological Information for Open Society* fosters collaborative “open source” development of key enabling technologies, such as tools of genetic transformation, that will be made freely available to developing countries. It is also a clearinghouse for databases from IPR offices to reduce transaction costs in acquiring intellectual property.
- *African Agricultural Technology Foundation* brokers the acquisition of intellectual property for smallholders in Africa, case-by-case, on a humanitarian basis. The foundation brokered the partnership of CIMMYT, the Kenya Agricultural Research Institute, BASF (a private producer of agrochemicals), the Forum for Organic Resource Management and Agricultural Technologies, seed companies, and NGOs to make the *Striga*-killing maize-herbicide technology available to smallholders in Kenya.

Sources: African Agricultural Technology Foundation (AATF) 2004; Wright and Pardey 2006.

Coordination can also be facilitated along the value chain by formalizing coordinating bodies or consortia of participants in a specific value chain.

Making R&D more responsive to farmers and the market

Formal R&D partnerships with farmers' organizations aim to enhance the demand for innovation by bringing farmers' voices into decision making. Collective action of this sort can identify constraints, pool indigenous knowledge, and aggregate technological demands. These partnerships help scale up adaptive research, testing, and dissemination—and facilitate access to inputs, markets, and finance for the new technologies.

Farmer organizations (chapter 6) have demonstrated strong interest in such partnerships. One approach empowers farmers by formally including them in governing councils of research organizations. This generally produces results only if the system is decentralized and farmers have a controlling interest in resource allocation—giving them the power to approve research projects and programs, as in Mexico (box 7.7).

Farmers have even more influence where they finance a significant share of R&D. The best-known examples of this approach use levies on commercial crops, such as cotton or coffee, governed by commodity-based producer organizations (for tea research in

Tanzania and coffee research in Colombia, for example). Widely adopted in industrial countries, such levies have been underused in developing countries, despite their potential to resolve underinvestment and improve the demand orientation and effectiveness of research.⁷⁴ In most cases, the levies are 0.5 percent or less of the value of commodity output. If matched by public funding, as in Australia and Uruguay,⁷⁵ they would allow a significant increase in research intensity in developing countries. Even where levies are not feasible,⁷⁶ donors and governments could still channel more funding through farmer organizations, especially for adaptive research—as in Mali, where Regional User Commissions manage funds for adaptive research.

The most successful partnerships combine farmer organizations with value chains and PPPs to integrate market demands (box 7.8). Funds are becoming more available to cofinance these partnerships. In Senegal, farmer organizations have strong decision-making powers in the National Agricultural Research Fund, which finances research carried out in partnership with private and development actors.

A big challenge in integrating farmer organizations into technological innovation is that their leaders are at an educational and social disadvantage relative to scientists and technical advisors. This gap is even more pronounced for poor and marginal groups and for women. Targeted capacity building and financing are usually required to empower weaker members and to ensure that farmer leaders fairly represent their interests.

BOX 7.7 *Mexican farmers lead research through PRODUCE foundations*

PRODUCE foundations,⁷³ farmer-led NGOs, were created in Mexico in 1996 to leverage additional funding for the cash-strapped national agricultural research institutes and to give producers a role in the funding and focus of agricultural R&D. The foundations help set priorities and approve and cofinance research projects in each state.

In 1998 the 32 foundations (one for each state) created a national coordinating office to help them become key players in Mexico's agricultural innovation system. They now lobby successfully for agricultural R&D.

The foundations have formal links with research and educational institutions, as

well as the National Council for Science and Technology. They also manage a trust fund, which has a mechanism for matching funds between the governments and producers.

The foundations are, however, the turf of commercial farmers. Attempts to integrate small farmers have failed because of high transaction costs in dealing with individual farmers and the difficulties in identifying small producers with an orientation toward commercial agriculture, the main emphasis of PRODUCE.

Sources: Ekboir and others 2006.

Using available technology better: extension and ICT innovations

There is general agreement about the considerable productivity and profitability gaps in most smallholder farming systems relative to what is economically attainable (chapter 2).⁷⁷ Lack of access to inputs and credit and the inability to bear risks explain part of the gaps (chapter 6). But one major reason is an information and skills gap that constrains the adoption of available

technologies and management practices or reduces their technical efficiency when adopted. Hence the recent emphasis is on new approaches to demand-led extension and to the application of new information and communications technologies (ICTs) to reduce these gaps.

New demand-led approaches to extension

Agricultural extension helps farmers learn how to augment their productivity, raise their incomes, and collaborate with one another and with agribusiness and agricultural research. Accordingly, extension programs are shifting from prescribing technological practices (delivery model) to focusing more on building capacity among rural people to identify and take advantage of available opportunities, both technical and economic (empowerment model). To perform such a wide-ranging role, extensionists must be trained in areas beyond technical agriculture to build skills in mobilizing farmers, tapping market intelligence, and managing farm and nonfarm businesses (see focus G).

Public services have dominated extension. Public spending for extension exceeds that for agricultural research in most developing countries. But public financing and provision face profound problems of incentives of civil servants for accountability to their clients, weak political commitments to extension and to agriculture more generally, extension workers not being abreast of relevant emerging technological and other developments, a severe lack of fiscal sustainability in many countries, and weak evidence of impact.

One of the most influential efforts to “fix” public extension was the training and visit (T&V) model of organizing extension, promoted by the World Bank from 1975 to 1995 in more than 70 countries. The T&V approach aimed to improve performance of extension systems by strengthening their management and formulating specific regular extension messages. But the T&V system exacerbated other weaknesses, especially fiscal sustainability and lack of real accountability. The result: widespread collapse of the structures introduced.⁷⁸

BOX 7.8 *Adding value to a poor farmer’s crop: cassava in Colombia and Ghana*

Cassava, traditionally viewed as a subsistence crop of the poor, is emerging as a strategic link in industrial value chains in Colombia, Ghana, and many other countries. Private-public farmer partnerships facilitated this transformation through greater coordination along the value chain—and through R&D within a broader context of new products and markets and greater competitiveness.

In Ghana, the Sustainable Uptake of Cassava as an Industrial Commodity Project established systems linking farmers, especially women, to new markets for cassava products, such as flour, baking products, and plywood adhesives. The local Food Research Institute and industrial users collaborated to organize more than 100 stakeholders into a value chain of cassava production and drying in rural areas, grinding and milling in central facilities, and distribution to industrial processors.

In Colombia, the International Center for Tropical Agriculture structured its early cassava research around dried cassava chips for the animal feed industry. Between 1980 and 1993, 101 cooperative and 37 private processing plants were built. By 1993 these facilities produced 35,000 tons of dried cassava, with an estimated value of \$6.2 million.

Since 2004 the Ministry of Agricultural and Rural Development has explicitly included cassava in competitive calls for R&D projects to stimulate further innovation and maintain competitiveness in value chains. High-value clones with enhanced nutritional quality, novel starch mutations, and sugary cassava have been identified and integrated into value chains for the animal feed, starch, and ethanol industries, respectively.

Source: World Bank (2006h).

From centralized to decentralized. In the 1990s many governments moved away from centralized systems and transferred to local governments the responsibility for delivering extension and, in some cases, financing it, in line with wider efforts to decentralize government (chapter 11). The expected advantages are to improve access to local information and better mobilize social capital for collective action. It should also improve accountability, as agents report to local stakeholders or become employees of local government, which—if democratically elected—would be keen on receiving positive feedback on the service from the client-voter. Although these are good reasons to decentralize extension, general difficulties in decentralization, as well as local political capture, have in some cases compromised progress in delivering more effective advisory services.⁷⁹

A promising additional element, increasingly adopted, is to involve farmers in decentralized governance. Since 2000, both the Agricultural Technology Management Agencies (ATMAs) in India and the National Agricultural and Livestock Program in Kenya have set up stakeholder forums from national to district and sub-district levels to plan and set priorities for

extension activities. Both promote farmer interest groups around specific crop and livestock activities, farmer-to-farmer learning and knowledge sharing, and marketing partnerships with the private sector. Based on favorable evaluations of the first phase (including an estimated 25 percent increase in farmer incomes in most ATMA districts, far more than the 5 percent in most neighboring districts), the two programs are being scaled up to the national level, and similar initiatives are under way in many other countries, such as Tanzania.⁸⁰

Mixing public and private. Other new approaches recognize the significant private-good attributes of many extension services, such as technical advice delivered by processors and wholesalers to farmers producing high-value crop and livestock products under contract (chapter 5). Mixed public-private systems involve farmer organizations, NGOs, and public agencies contracting out extension services. The various approaches are now often found alongside each other, in a shift from a “best practice” or “one-size-fits-all” to a “best fit” approach to particular social and market conditions. For example, approaches based on public funding but with involvement of the local governments, private sector, NGOs, and producer organizations in extension delivery may be most relevant to subsistence-oriented farmers (table 7.3). With agricultural commercialization, various forms of private

cofinancing are appropriate, through to full privatization for some services. In all these efforts to make agricultural innovation systems more demand driven, there is a need to pay attention to how women’s demands can be better represented, accommodating their time constraints (in, say, participating in farmer organizations), and employing them in advisory services to increase effectiveness of service delivery.⁸¹

As in research, building demand is part of successful extension. Management may become the responsibility of farmer or agribusiness organizations rather than local governments. Extension can still be publicly funded, but funds can flow through farmer organizations that have a controlling interest in fund allocation (figure 7.3). Farmer organizations, in turn, may contract out extension services to private providers and NGOs, as in Uganda’s National Agricultural Advisory Services, viewed by farmers as working well.⁸² Another approach is to have a private company and the state extension system jointly finance and provide advisory services, especially for agrochemical inputs, as in Madhya Pradesh, India.⁸³

Farmer to farmer. Extension methods have also become more diverse, including farmer-to-farmer extension. Informal networks among farmers have always been powerful channels for exchanging information and seeds. Several programs are formalizing and linking such networks for

Table 7.3 Ways of providing and financing agricultural advisory services

Provider of the service	Source of finance for the service				
	Public sector	Farmers	Private firms	NGOs	Producer organizations (POs)
Public sector	Public sector advisory services with decentralization	Fee-based services	..	NGOs contract staff from public extension services	POs contract staff from public extension services
Private firms	Publicly funded contracts to service providers	Fee-based services or by input dealers	Information provided with input sales or marketing of products	..	POs contract staff from private service providers
NGOs	Publicly funded contracts to service providers	Fee-based services	..	NGOs hire staff and provide services	..
Producer organizations	Public funds managed by farmer organizations	POs hire extension staff to provide services to members

Source: Birner and others (2006).

n.a. = not applicable.

.. = negligible in practice.

knowledge sharing and learning. The Programa Campesino a Campesino in Nicaragua and the Mviwata network in Tanzania provide national coverage through farmer-to-farmer approaches.⁸⁴

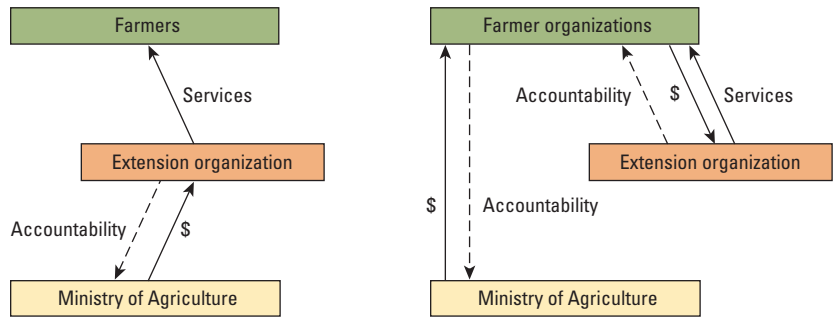
A related approach is the Farmer Field School, originally designed as a way to introduce integrated pest management to irrigated rice farmers in Asia. The schools have been introduced, often on a pilot basis, in some 80 developing countries, and their scope has been broadened to other types of technology.⁸⁵ Impact evaluations, still limited, have shown that the approach can significantly improve farmers' knowledge of new technological options, but the schools have not demonstrated the cost effectiveness hoped for in service delivery.⁸⁶ This may be because complex management information, such as that for integrated pest management, does not travel as easily from farmer to farmer as information on seed of improved varieties. It is also because benefits from the management skills acquired need to be observed over the long run.

Back on the agenda. Agricultural extension services, after a period of neglect, are now back on the development agenda, with a sense of excitement about many of the emerging institutional innovations. Clearly there still is much to do in bringing needed extension services to smallholders around the world, especially the poorest groups. Understanding what works well in the diverse circumstances of the developing world remains a challenge, of course. More evaluation, learning, and knowledge sharing are required to capitalize on this renewed momentum.

New ICT tools at the farm level

The declining costs of ICTs are giving farmers and rural people in developing countries much greater access to information. In China, 83 percent of villages now have fixed phones, and 56 percent have mobile coverage. In India, 77 percent of villages have fixed phones, and 19 percent have mobile coverage. Mobile phone coverage in India is expanding at breakneck speed—on one day in 2006, Nokia sold more than 400,000 new mobile phone handsets, and new sub-

Figure 7.3 Financing for extension services, the traditional and the new approach



Source: Chipeta 2006.

scriptions are averaging 6 million a month, many in rural areas.

In Africa, about 9 percent of the population have mobile phones in networks that could reach 60 percent of the population. In Uganda, 80 percent of communities have mobile phone coverage, and 5 percent of households possess mobile phones.⁸⁷ The broader coverage, more than the possession of individual mobile phones, induces market participation by reducing transaction costs in crop marketing and increasing prices, especially for perishable goods.⁸⁸ The Kenya Agricultural Commodity Exchange and Safaricom Limited collect and disseminate current and reliable commodity price information to Kenyan farmers through a low-cost Short Message Service (SMS) provider.

Farmers also use ICTs for extension advice from a range of sources, but it takes time to develop demand-driven services. Private operators and an NGO in India reach tens of thousands of farmers and are being rapidly scaled up (box 7.9). Computers are now being linked through mobile phone networks to greatly expand the scope of information. The soon-to-be-launched “\$100 laptop” could herald an even greater role for ICTs.⁸⁹

Policies to improve ICT access in rural areas need to focus as much on content and education as on infrastructure. Education is one of the key factors affecting the return to ICTs in agricultural production, along with electricity, roads, and appropriate business models.⁹⁰ Local content creation needs to be linked to institutional innovations to provide farmer-responsive extension services.

BOX 7.9 *Private agribusiness and NGOs: leading ICT provision to farmers in India*

Indian private companies and NGOs are global leaders in providing information to farmers, as a spinoff from India's meteoric rise as a world leader in ICTs. The e-Choupals (chapter 5) now provide information on the weather and farming techniques in local languages, in addition to information on market prices.

The M. S. Swaminathan Research Foundation established Knowledge Centers in Pondicherry in 1997. With the support of the Indian Space Research Organization, centers in each village are connected by satellite to a hub at Villianur. The centers are managed by women's self-help groups, which receive microcredit loans and training to start small businesses such as mushroom or biopesticide production.

The self-help groups use the centers' computers to manage their business accounts and coordinate their activities, using video links with the other villages.

Farmers can use the centers to access databases of technical information, developed by the hub, with the help of experts from local agricultural institutions, in their local language. Dairy farmers, for example, have received training in some centers using touch-screen computer applications developed by the local veterinary college. An alliance of more than 80 partner organizations extends the concept throughout India.

Source: M.S. Swaminathan Research Foundation (MSSRF) 2005.

Moving forward

Science and technological innovation are critical for the agriculture-for-development agenda to succeed on four fronts. First, at a global level, science will become even more important to meet growing demand in the face of rising resource constraints and energy costs. Second, in all countries, science and innovation are central for maintaining market competitiveness, both domestic and global. Third, the potential of science to address poverty in both favored and less-favored regions has yet to be fully tapped. Tailoring technologies to growing heterogeneity among farmers and to differentiated needs of men and women farmers remains a scientific and institutional challenge. And fourth, science will be critical in adapting to and mitigating climate change and tackling environmental problems more generally.

With current R&D policies likely to leave many developing countries as agricultural technology orphans in the decades ahead, the need to increase funding for

agricultural R&D throughout the developing world cannot be overstated. Without more investment, many countries may continue to lose ground in the ability to adapt new knowledge and technologies developed elsewhere and ensure competitiveness. The greatest urgency is to reverse the stagnant funding of agricultural R&D and broader knowledge systems in Sub-Saharan Africa. This reversal must be driven by national leadership and funding, but it will require substantially increased and sustained support from regional and international organizations.

Continuing progress, especially in extending benefits of R&D to agriculture-based countries and less-favored regions elsewhere, depends on research in these environments for improving crop, soil, water, and livestock management and for developing more sustainable and resilient agricultural systems. These technological innovations, often location specific, must be combined with institutional innovations to ensure that input and output markets, financial services, and farmer organizations are in place for broad-based productivity growth.

Low spending on R&D is only part of the problem. Many public research organizations face serious institutional constraints that inhibit their effectiveness and thus their ability to attract funds. Major reform is required. Likewise, old-style agricultural extension is giving way to a variety of new approaches to funding and delivery that involve multiple actors. The rise of higher-value markets is creating new opportunities in the private sector to foster innovation along the value chain, involving cooperation among the public sector, private sector, farmers, and civil society organizations. What is needed now is to better understand what works well in what context and scale up emerging successes.