6 Sources of agricultural growth

Farming has come a long way since man learned to cultivate plants 10,000 years ago. The constraints of soil and climate have gradually been eased. Virgin land has been settled, its productivity raised. Hands have been helped by hoes, then by plows and animals, and finally by sophisticated machines. The search for new and better farming methods continues, assisted by the full weight of scientific research.

Until the 1950s, agricultural progress in most developing countries was slow and uneven, barely keeping pace with population growth. Although the expansion of agricultural trade had boosted tropical exports, farming for food was largely neglected during the colonial period. In the past twenty years, however, great strides have been made. Hundreds of millions of people, from peasants farming a few acres in Kenya to commune members in China, have transformed the ways in which they farm the land. They have been assisted by science, and spurred on by the prospect of higher incomes and security for their families. Their considerable achievements cannot obscure the size of the challenge that still lies ahead, however. Many developing countries’ populations are growing faster than their agricultural production, and many millions of farmers have not yet shared in the progress of the past twenty years.

The reasons for this patchy progress are the main focus of this chapter. It examines the sources of agricultural growth, paying special attention to the role of science and technology in discovering new farming methods. The task of adapting those discoveries to the circumstances of particular countries and people; of disseminating the results and encouraging farmers to adopt them; of providing the numerous back-up services that are then needed to turn good intentions into concrete results—these are the themes that will recur repeatedly. Throughout, the discussion shows how agricultural success flows from a unique combination of private and public endeavor. Government can supply some of the support and incentives from which all farmers can benefit but which none could organize independently. It is then for farmers to take the inevitable risks associated with large rewards.

As noted in Chapter 5, agricultural progress has been remarkably successful in many ways during recent years, and the prime source of growth has been food production in the developing countries. Differences in soil and climate have produced an almost infinite variety of cropping systems in these countries. Five main crop zones can be identified, however, on the basis of the staple food crop that predominates in each (see Figures 6.1 and 6.2).

- Rice, which first grew on the water-retentive soils in the humid tropics of Asia, has been adapted to fit a wide range of environments. Farmers now grow rice in the river valleys and coastal plains of South China, South and Southeast Asia, the Indonesian and the Philippine islands, Japan, and Korea, as well as small areas of Latin America and East and West Africa. In many nearby high-rainfall areas with more permeable soils, upland rice is grown with other crops.

- Starchy root crops (cassava, yams) are grown in areas of the humid tropics where soils are less fertile and not well suited for cereal cultivation, such as western and central Africa and parts of Oceania and Latin America. Cassava has also spread to northern Thailand where it has emerged as an important export crop.

- Maize is the most important staple in the subhumid tropics of Latin America and Africa. The most common crops farmed with maize are cotton, groundnuts, soybeans, and sorghum in the drier areas; coffee, cocoa, and starchy root crops in the wetter areas.

- Sorghum is the main food grain in the wetter parts of the semi-arid tropics and millet in the drier regions. Groundnuts, cotton, cowpeas, and pigeon peas are the most common associated crops.

- Wheat is the most important
grain in much of the temperate zone but is grown over an increasing area of the cooler tropics as a winter crop in association with monsoon-grown grains or cotton.

The first section of this chapter deals with land, noting in particular the increasingly limited role which settlement of new land will play in agricultural expansion. The second section examines the alternative to settlement—intensive agricultural development—as a source of growth and discusses the important contributions made by irrigation, intensified farming in rain-fed areas, and livestock development. Two sections follow on the prime forces behind intensive development: technology (machinery, pesticides, her-
bicities, and fertilizers) and research, together with their results (the Green Revolution in cereals and progress in other tropical crops). The chapter concludes with a discussion of some of the key elements of ongoing support for agriculture: infrastructure, extension, marketing, and credit.

Land

For centuries, farmers increased their output mainly by increasing the amount of land they farmed. This is no longer the case: in the past two decades, increased acreage has accounted for less than one-fifth of the growth in agricultural production in developing countries (see Figure 6.3), and for an even smaller fraction in developed countries. Nonetheless, there is still a great deal of unused arable land—estimates for developing countries range from 500 million to 1.4 billion hectares, compared with about 820 million hectares currently under cultivation.

These estimates can mislead, however. The unused land is not where the people are who need it most, and FAO reckons that only 10 to 15 percent of unused arable land in 1980 might be cultivated by 2000. There is ample cultivable land in the humid and subhumid parts of Latin America and sub-Saharan Africa, but reserves in the Mediterranean area and most of Asia (except Indonesia) are extremely limited. China has reached the limits of its arable land, and a number of other countries are fast approaching this point.

The imbalance between people and land reserves is only one factor limiting the development of more acreage. Disease has discouraged permanent settlement in large parts of the tropics and subtropics. The eradication of
malaria in the 1950s opened extensive new areas for cultivation, especially in Asia. Today, the main diseases constraining settlement and cultivation are river blindness (onchocerciasis) and sleeping sickness (trypanosomiasis), which occur primarily in sub-Saharan Africa.

To avoid river blindness, large areas have been left unfarmed in the fertile valleys of the Volta, Niger, Congo, Gambia, and Upper Nile rivers. Efforts to eradicate this disease are supported by West African governments, WHO, FAO, the World Bank, and bilateral donors, but progress is slow. Trypanosomiasis, carried by the tsetse fly, is an even greater obstacle. Its presence prevents livestock-based farming on some 1 billion hectares of high rainfall land in Africa. Insecticides have been tried in several countries, including Nigeria, Cameroon, and Botswana, but their cost and the tsetse fly’s resistance underline the need for more research to find effective solutions.

Most expansion of farmland takes place spontaneously, as farmers move into forests and grazing areas. Farmers are also gradually switching to permanent cultivation, especially in Africa, and are reducing fallow periods. In the rare instances of extensive virgin areas with good soil—northwestern Brazil for example—migration is taking place on a large scale. It has significantly boosted output in Brazil, Thailand, and the Philippines. Even in recent times, migration has been the major, often the only source of agricultural growth in sub-Saharan Africa.

The advantage of spontaneous settlement is that it is cheap and the costs are born by the settlers themselves. People do not always have the assets or the incentive to move, however, even in countries where land is available. Some governments have sponsored settlement schemes: for example in Malaysia and in the outer islands of Indonesia. Generally, though, such schemes are expensive. They typically cost $1,000 to $2,000 per hectare for clearing land and providing roads, markets, schools, and health facilities.

In the early stages of migration, farmers move to the most attractive land. Later, as population pressures force them into more marginal areas, their arrival causes erosion and declining soil fertility. Deforestation is a particular problem. Between 1900 and 1965 about half the forest area in developing countries was cleared for agriculture. Although forests still cover half the land in the humid and subhumid tropics, forest cover has been reduced to 10 to 15 percent in the semi-arid tropics and the temperate zone.

Massive deforestation has highlighted the virtues of forests. They regulate the pace at which rainfall runs off, prevent soil erosion, replenish nutrients in the soil, and influence the local climate. These qualities can be retained as long as cultivation is

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**Box 6.1 Forests and fuelwood: The Sahel’s ecological dilemma**

Forests play a vital role in the ecological balance as habitats for flora and fauna, anchors for soils, and tamers of climates. In the Sahel, however, forests are endangered by a rapidly growing population’s need for forest products for fuelwood and building material.

As a result of progressive deforestation, rural household members have to walk farther and farther to collect fuelwood; in some areas, almost half a rural family’s working time can be spent gathering supplies. Meanwhile the average urban household, which uses between 3 and 5 cubic meters of wood a year, spends an increasing part of its budget on fuelwood. In some Sahelian towns, it often "costs more to heat a pot than to fill it."

If they are to maintain a bare minimum of forest cover, most Sahelian countries will have to halve their fuelwood consumption by the turn of the century. Reductions can be achieved by promoting efficient wood-burning stoves and the use of substitutes for fuelwood, such as commercial fuels or crop and animal residues. Massive afforestation is another strategy, but the technical and sociopolitical constraints are awesome. Few Sahelian countries can count on more than 800 millimeters of rainfall a year, and its incidence is erratic. Trees are hard to establish in the arid zone and grow slowly. Most forests are publicly owned, but the long-term benefits of conservation conflict with short-term private needs. Government policy, trying to balance individual and community interests, is ambivalent. Few people are interested in conservation or afforestation, and the few forestry programs attempted have generally been disappointing.

Following the last drought in the area, the World Bank and other donor agencies have begun to help Sahelian countries finance forestry projects. Most of these pilot and technical assistance projects were initiated in the late 1970s and are based on the use of conventional techniques of forest management and afforestation. They do not initially focus on the rapid expansion of forestry. Instead, they are directed toward improving the training, planning, managerial, and operational capabilities of the institutions that manage forests. Several programs include components to train forestry extension staff and to test alternative ways of winning the support of local populations for forest conservation and new planting. Increasing emphasis is being given to planting multipurpose trees that can provide a combination of fuelwood, building poles, and timber. Leguminous tree species, which fix nitrogen and improve soil fertility, are favored in areas where ecological conditions are suitable for their growth.
shifting, rather than permanent, and if the commercial extraction of lumber is carefully controlled. In countries such as Brazil and the Philippines, serious damage has been caused by the failure to enforce limits on felling trees and clearing forests. The worst damage occurs, however, in cases where forests are treated as unlimited sources of fuelwood. Some four-fifths of all wood cut down in developing countries is used for fuel. The problem is most severe in densely populated hill areas (such as the Andes and the Himalayas) and in semi-arid and arid areas, where the desert creep up as the forest retreats.

If the consequences of deforestation are serious, so are its causes. Millions of people depend on wood for their fuel; in sub-Saharan Africa it provides three-quarters of all the energy used. The solutions lie partly in developing new supplies of energy and partly in more effective conservation of forests. Since farmers see no immediate advantage in such conservation, public bodies have the dominant role to play (see Box 6.1).

Intensive agricultural development

New land has been a significant source of past growth, but its future role is plainly limited to a few countries. The alternative is to use existing land more efficiently. Efforts to do so have been highly successful; the average productivity of cultivated land has been growing at about 2.2 percent a year for the past twenty years (see Figure 6.3). Except in the semi-arid sorghum and millet zone, higher yields account for more than half the growth of output. In the mixed cropping zones of China, agricultural acreage has actually declined while yields have increased by nearly 3 percent a year.

These productivity gains have been achieved largely by improving the availability and reliability of irrigation and increasing the use of new seeds and fertilizer (see Figure 6.4); significant progress has also been made in regions with dependable rainfall.

Irrigation

Irrigation has made the largest contribution to increased agricultural production in much of Asia, North Africa, and the Middle East. In many areas it can double or treble yields during the main growing season, can make a second or even a third crop possible, and can sharply reduce the risk of crop failure. Such programs can also have multiple effects throughout the economy (see Box 6.2). These advantages need to be set against two drawbacks: ground and surface water for irrigation is not available in large parts of the world, and the infrastructure is expensive.

Box 6.2 Downstream effects of irrigation

The direct benefits of investment in agriculture, particularly for irrigation projects, are not hard to identify and measure. Construction jobs are created, agricultural output increases, consumers may benefit from lower food prices, and farm income is likely to rise. In addition, however, such projects can have much more widely dispersed but less easily measured benefits.

Careful monitoring of an irrigation project in the Muda region of Malaysia gave the World Bank a chance to look into the indirect, downstream effects of this $240 million program for increasing paddy production, which was approved in 1972. Using a battery of sophisticated analytical tools, the Bank asked:

- Who, besides producers, benefits from the program?
- What is the overall impact on the economy?
- What additional investments may be induced?

The answers to these questions were impressive. For every dollar of increased paddy output, about 0.75 of income was also generated in the downstream effects. In other words, farmers' increased income from paddy generated demand for goods and services equivalent to 43 percent of total benefits of the scheme. This demand was mainly in such sectors as housing and other construction, commerce, road transport, and hotel and restaurant services—all of which are quite labor-intensive activities in rural Malaysia. Higher earnings in these sectors in turn multiplied jobs and incomes for workers in still other parts of the economy.

There is more to the story, however. Rice needs to be milled, and mills have to invest in plant and equipment. The Muda project induced an estimated net $56 million of private investment, which in turn had further multiplier effects.

Who received the benefits? Research provides some answers. Participating paddy farmers' incomes rose about 70 percent, but landless farm workers' more modest earnings rose still more (73 percent). Even the incomes of nonfarmers and nonparticipating farmers in the region rose (by 14 percent and 10 percent, respectively) by comparison with what they would have been without the project.
Investment for irrigation has risen dramatically in developing countries, to around $15 billion in 1980. The irrigated area has grown by 2.2 percent a year since 1960. Some 160 million hectares, one-fifth of the harvested land in developing countries, is now irrigated. This land area uses about 60 percent of all fertilizer and produces over 40 percent of all annual crops in the developing world. Between 50 and 60 percent of the increase in agricultural output in the past twenty years has come from new or rehabilitated irrigated areas. China (with 49 million irrigated hectares) and India (with 39 million) account for more than half the developing world’s irrigated area (see Figure 6.5).

Irrigation absorbs a large part of public sector investment, especially in low-income countries. Frequently, low water charges and inadequate taxes on agricultural incomes have made the burden on the government’s budget heavier than it needs to be. A relatively modest (50,000-hectare) scheme can cost between $100 million and $200 million. To ensure a reasonable return on that investment, the system has to be carefully designed and organized, and then fully used. Efficiency has become increasingly critical, partly because of actual or threatened water shortages. More important, modern, high-yielding seeds require reliable supplies of water at specified times if they are to fulfill their promise. A timely and reliable water supply also enhances the farmers’ willingness to pay water charges.

In India and Sudan, both of which have extensive irrigation experience, large canal schemes with storage reservoirs require an investment of about $2,000 a hectare. Similar schemes in East and West Africa often cost more than $10,000 a hectare, the result of an inexperienced domestic construction industry and dependence on imported materials and equipment. Such costs can be justified in only a few countries—for example, those in the Mediterranean basin—where advanced methods of water management ensure the efficient use of the system and market demand for the high-value crops produced is strong.

Increasing the efficiency of existing irrigation schemes offers considerable scope for faster growth, since yields are well below their potential in many areas and water is wasted. Poor design and construction of the tertiary channels that bring water to farmers’ fields help explain the inefficiency of irrigation systems. Recent studies have demonstrated, however, that in most projects inadequate design and neglect of the main canal system are the major causes of inequitable and wasteful use of water in the fields. Many existing irrigation systems suffer from waterlogging and salinity because of lack of drainage, particularly in northern China, Egypt, northern India, and Pakistan. More than half of the Indus Basin Canal system in Pakistan, some 8 million hectares, is waterlogged and 40 percent is saline.

Shortages of trained staff—partly the result of their being lured away by new engineering ventures—have sometimes prevented improvements. Once built, irrigation schemes are often managed by design and construction engineers who have little training in water management or agriculture. In some countries with strong civil service demarcations, engineers are the only people entitled to work in the irrigation service. Their expertise needs to be joined with that of others, and farmers themselves should be involved in irrigation programs from their inception.

In addition to large public sector irrigation schemes, there has been a rapid expansion of private irrigation. The development of cheap pumps and the introduction of modern seed and fertilizer have brought irrigation within the means of millions of small farmers. In South Asia since 1960, farmers have invested about $15 billion in open wells and tube-wells irrigating 30 million hectares. These private schemes, supported by the public sector’s provision of long-term credit and rural electrification, comprise as large an area as all public and private irrigation in North Africa, the
Middle East, and Latin America. Elsewhere, tubewell and pump irrigation has grown slowly, particularly in sub-Saharan Africa. Irrigation is not economic in much of sub-Saharan Africa, though it is also constrained by inadequate water surveys and the lack of a supporting infrastructure. In parts of the savannah belt of northern Nigeria, for example, studies indicate that tubewell and pumping schemes would be economically justified. Though more expensive to operate and maintain than canal systems, pumps and tubewells often prove more effective, because they can be managed more easily and the initial investment is much smaller.

Rain-fed areas

While irrigation has many advantages, the fact remains that rain-fed areas constitute 80 percent of the developing world’s cultivated land and support nearly two-thirds of its farmers. Yield increases still depend on the subtle interaction between soil, water, seeds, and sunlight, but the process is not as well understood under rain-fed conditions as it is with irrigated land. Local conditions vary so much that finding solutions is often costly, and they can seldom be replicated elsewhere. Even with the current state of knowledge, however, there is scope for growth. New methods of tilling, new crop rotations, increasing use of fertilizers and pesticides, soil conservation and drainage—all have a part to play. Tackling the problems of rain-fed agriculture is an increasingly important challenge in many countries, including some such as Mexico (see Box 6.3) where irrigation has already been extended as far as possible.

Soil erosion and declining fertility are the main threats to rain-fed agriculture in the humid and subhumid tropics. Tackling them requires protecting the soil by continuous crop coverage and minimum tillage, as well as drilling seeds and controlling weeds. This kind of systematic approach is being developed at IITA in Nigeria. (See Glossary and Box 6.4 for names and functions of international agricultural research centers.) In the case of some Latin American countries, highly acidic, infertile soils present a rather different challenge. There, research focuses on reclamation, new crop rotations, and more effective means of fertilizing the soil. In areas with relatively dependable rainfall and moisture-retentive soil, ICRISAT is developing new cultivation methods. These are based on semi-permanent broadbeds and furrows that provide drainage in heavy rains and improve the soil’s capacity to retain moisture. Together with pre-

**Box 6.3 Rain-fed agriculture: The Mexican experience**

In the 1950s and early 1960s, Mexican agriculture had one of the highest growth rates in the world, averaging 4 to 7 percent every year. Performance was largely based on technology improvements closely linked to expanding irrigation. Between 1940 and 1965, about 90 percent of all public investment in agriculture was for irrigation.

Growth slowed markedly in the 1970s. New irrigation became increasingly expensive (and old systems harder to maintain); meanwhile poverty remained endemic among the 87 percent of Mexico’s farmers who lacked irrigation. The combination led the Mexican authorities to look for answers in rain-fed farming. Fortunately, Mexico’s rain-fed areas have high potential for agricultural production. The Plan Puebla, the first rain-fed development project of its kind, started in 1967, had shown that farmers could triple or quadruple maize yields with new plant varieties and farming methods, and at a lower cost than through investments in irrigation. Production could be diversified into higher-value crops. Moreover, much potentially arable land with adequate rainfall was being used only for extensive livestock grazing and could be put to more intensive use.

The new policy tilt has involved some major changes. First, it was necessary to upgrade the efficieny of extension services and credit provision to farmers in rain-fed areas, and to make access to land easier by improving rural roads. Second, land tenure laws had to be changed and wetland drainage installed to encourage farmers to cultivate little-used land more intensively. And third, guaranteed producer prices and subsidized inputs needed to be offered for crops such as maize and beans typically grown on rain-fed farms.

These new approaches were embodied in a series of programs which received substantial World Bank assistance. In the PIDER program (started in 1973) the objective has been to bring an integrated package of services—extension, research, credit, roads, irrigation, potable water supply, and education—to small, well-defined areas of generally low-income rural communities. As the coordination of services through the federal government became a bottleneck, control of the programs was decentralized from the federal to the state level. In 1979, the government established 118 Rain-fed Districts (Distritos de Temporal) throughout the country, on the pattern of the existing Irrigation Districts. This made it possible to have an integrated approach to rain-fed land development while at the same time taking into account local physical conditions, which vary widely.

These efforts have laid a solid base for future structural change and increased and diversified production in Mexico’s rain-fed agriculture. Concrete results are apparent in the response to improved production incentives announced two years ago. After a decade of slow growth (2 to 3 percent a year), agricultural production increased by 5.5 percent in 1980 and by 8 percent in 1981, most of it from rain-fed cultivation.
monsoon sowing, changed crop rotations, high-yielding varieties, and fertilizer, this approach has tripled output in farm experiments.

Though promising, these new efforts will require extensive testing on farms before they can be widely applied. Increases in yields from rain-fed land will therefore be relatively slow and concentrated in regions with better rainfall and soil. But the gains could be considerable. If rain-fed land could increase its yield by 500 kil-

Box 6.4 New frontiers in agricultural science

Modern plant breeding dates from the mid-nineteenth century, when Mendel identified the laws of genetic inheritance. The application of Mendelian techniques, together with the knowledge of plant nutrition discovered by Liebig, has permitted dramatic increases in the productivity of major cereal crops around the world. These have culminated in what has come to be known as the Green Revolution. The next quantum leap has taken place only recently with the discovery of deoxyribonucleic acid (DNA), a complex chemical that is the carrier of the transmitted characteristics of all living things. This has opened up vast new opportunities to manipulate nature. Entirely new organisms can be created by transposing character-transmitting particles of matter, or genes, from one species to another.

The potential of genetic engineering is not yet fully known. New knowledge is being acquired at an unprecedented rate as a result of research around the world by academic and commercial organizations, but this work is still in its infancy; it may be decades before wholly new species of commercial value become available. The genetics of even single-celled organisms such as bacteria are not yet fully understood. Meanwhile, however, immediate gains can be made by exploiting other elements of the fund of new knowledge about biological systems.

**Tissue culture**—the multiplication of plants through in-vitro micropropagation—holds special promise. Starting in some cases with simple vegetative material, a piece of leaf or an excised root tip, manipulation and hormonal treatment produce a proliferation of callus, an undifferentiated mass of cells. Further treatment makes the callus reorganize and form embryo-like structures which go on to develop into completely new plants. These are genetically identical in every respect with the parent plant. Tissue culturing became commercially viable about twenty years ago, initially for ornamental plants and later for vegetables and fruits such as asparagus and strawberries.

By the late 1970s, tissue culturing had been achieved with many woody species, including temperate fruit crops such as apples and pears, several of the developing world’s important perennial crops (such as coffee, rubber, and oil palms), and a number of tropical forest tree species. It is now generally believed that all plant cells are potentially "totipotent," that is, they have the ability, under suitable conditions, to grow into complete plants. Tissue culture permits very much faster multiplication rates than those attainable by seeding or conventional propagation techniques such as budding and grafting. Moreover, the genetically identical material derived from these cultures gives uniformity of yield, quality, and rate of ripening. Tissue culturing can also be used to develop disease resistance and adaptability to specific habitats.

Not all species that can be cultured in the laboratory can yet be propagated on a commercial scale. Tissue cultures could, however, provide a basis for yield improvements in tropical perennial crops comparable with the impact of the Green Revolution on the cultivation of cereals. Clonal oil palms are already being field-tested on plantations in Malaysia. One commercial company expects by the mid-1980s to be marketing clones with a proven capacity for high yields, and there is a possibility of producing several million plants a year by the end of the decade. Productivity is expected to be enhanced by at least 30 percent over that of the best seedling progenies available today. Even more exciting prospects for yield improvement are offered by the possibility of clonal propagation of coconuts. The creation of clones from elite dwarf and tall hybrid populations could well double the highest yields now realized.

A different area of research, and one of less immediate practical application, attempts to help plants meet their nitrogen requirements from the atmosphere through **nitrogen fixation**. At present only leguminous plants of the pea and bean family can do this. The fixation mechanism involves a mutually beneficial, or symbiotic, relationship between the host plant and certain species of bacteria which live in nodules that develop on the plant's roots. The bacteria, deriving shelter and other vital support from the plant, are able to take up or "fix" atmospheric nitrogen. Some of this nitrogen is used by the host plant; some goes to enrich the soil.

Increasing the efficiency of this process in legumes, or finding ways of inducing the same symbiotic relationship between bacteria and nonleguminous plants, could revolutionize plant nutrition. Nitrogen, the most costly of the major plant nutrients when supplied in the form of chemical fertilizers, would become freely available from the atmosphere.

Work on nitrogen fixation is going on at many centers around the world. The International Network of Legume Inoculation Trials seeks new rhizobial bacteria that are superior nitrogen fixers, and aims to propagate and disseminate them worldwide. Farmers who are today remote from supplies and cannot afford to buy nitrogenous fertilizers may in time be able to realize yield increases that are currently beyond their reach.

Most of the scientists who are currently pushing back the frontiers of agricultural research are working in the developed countries. Some of the most exciting applications of the new technology, however, are expected to be in the realms of tropical agriculture.
ograms per hectare, the total increase in production would exceed what could be achieved by a rise of two tons per hectare in the yield of all irrigated land.

Some formidable obstacles stand in the way of such achievements. Not least among them is flooding: in many parts of the developing world, "normal" rains cause widespread floods. Standing water often more than 30 centimeters deep makes many paddy fields of Asia unsuitable for high-yielding dwarf varieties of rice. Small-scale flood protection and effective drainage would enable modern rice technology to expand into parts of Bangladesh, Burma, eastern India, and Thailand where it currently cannot be used.

Large-scale drainage and flood control programs are so expensive that it is often difficult to justify them on economic grounds alone. Individual countries can seldom afford them; in a few cases, the solution lies in joint efforts, because the benefits will be shared by more than one country.

Livestock

Though of relatively small economic importance today in many low-income countries, livestock farming could well expand rapidly in the future. It is already doing so in middle-income countries (see Table 6.1). Since animal products are a more expensive source of calories and protein than vegetable products, poor people

- In developed countries, strong demand for milk and meat, combined with well-organized marketing and processing industries, has commercialized farming to a high degree. Farmers usually specialize in one type of production, whether it be beef feed-lots, cattle ranches, or "factory farming" of milk, pork, beef, and eggs. Animals are bred specially to fit into these farming methods.

- In developing countries, a high proportion of farms combine

Table 6.1 Changes in the structure of agricultural output by subsector and region, 1961-65 and 1976-80 (percent)

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Source: FAO.

a. Estimated; excluded from totals.
have expanded rapidly over the past fifteen years and become increasingly intensive. The technology involved is readily transferable, but it requires relatively large quantities of feed grain and oilseed meals, which often have to be imported.

These new enterprises are often in competition with traditional livestock farming, which may suffer in consequence. Since productivity is much higher in intensive livestock farming, prices and costs have fallen sharply. Poultry has gone from being the most expensive to the cheapest meat, a major result of the 5 to 10 percent annual growth of poultry production in most developing countries.

Livestock farming in the arid natural grasslands of the developing world continues to face some intractable obstacles to growth. Animals need a great deal of land; in these areas it is often of poor quality and ownership may be ill defined. In much of the African Sahel, for instance, rangelands are common property. Improving their quality would be in the interest of all; actually investing to do so makes no sense for individual farmers. As a result, improvements are seldom made and farmers often overgraze. Resolving this problem is likely to require such measures as direct public control of herd movements and sizes or legal and institutional changes in the pattern of landownership.

Technology

The drive to improve the quality and productivity of farmland has been greatly assisted by the achievements and products of industry. Among the most important contributions have been the following.

Machinery

The speed at which farming becomes mechanized depends on the relative scarcities of land and labor, unless governments subsidize mechanization. In most of Asia and other areas with abundant labor, machines are used first for operations where concentrated power or speed are superior to human labor or animal-drawn implements: examples include stationary threshers, mills, and water pumps. Tractors are used for clearing heavy land and also for transport (Figure 6.6). In recent years, power tillers have been used for mechanized puddling of rice fields in, for example, Thailand and the Philippines.

The shift to mechanical power in response to labor shortages and rising real wages is very selective. Irrigation pumps, for example, are used widely in Bangladesh, but tractors are virtually nonexistent; mechanical rice threshers are used in central Thailand, where threshing of the first crop overlaps with the planting of the second, but the more labor-intensive method of buffalo-treading remains common in single-cropped areas.

Pesticides and herbicides

Estimates of crop losses because of insects, pests, disease, and weeds vary widely—from as low as 5 to 10 percent to as high as 30 to 40 percent. There is no doubt, though, that the rapidly spreading use of chemicals against insects and insect-borne diseases in recent years has greatly boosted crop production. Pesticides are often crucial for preventing losses of high-yielding crops. At the same time, their undesirable side effects are causes of genuine concern. Pesticides can change insects' immunities, destroy natural enemies, cause outbreaks of secondary pests, and deposit potentially harmful residues.

The alternatives to pesticides also have their drawbacks. One promising possibility is the promotion of wider genetic resistance to disease. This can be combined with crop rotations, efforts to introduce natural enemies that will attack predators and the sources of disease, and more discriminating use of chemicals. This kind of integrated pest management is complicated to administer, however. It requires teams of skilled scientists and a comprehensive organization for protecting crops. These requirements are far beyond the administrative capacity of most countries; nonetheless, selected elements of this approach can be highly effective.

Herbicides, which kill weeds,
have a primarily labor-saving function. They are particularly valuable where land is abundant and labor for tilling and weeding is scarce enough to limit the area that can be planted. Again, experience is showing how herbicides can be used more sparingly and to greater effect: one example is the zero-tillage system for the subhumid tropics being developed by IITA in Nigeria. The introduction of herbicides needs to be carefully monitored for its effect on both health and employment.

**Fertilizer**

Until the early 1960s, the use of fertilizer in developing countries was limited to a few valuable export crops. With the spread of irrigation and the advent of high-yielding seeds, fertilizer use rose eightfold, reaching 38 million tons in 1979. Half the increase in grain yields since 1950 is a result of greater fertilizer use in combination with irrigation and modern seeds. Most regional differences in the use of fertilizer can be explained by the amount of control farmers can exercise over their water supplies (Figure 6.7). In low-rainfall areas, only 3 kilograms per hectare of fertilizer (measured in terms of plant nutrients) are applied, while high-rainfall areas average 20 kilograms per hectare; with reliable irrigation, about 110 kilograms per hectare are used. Farmers use little fertilizer in drier areas because plants that lack water do not respond, and the risk of crop failure makes farmers reluctant to use it. To some extent this is also the case with some irrigation systems that do not ensure an adequate water supply.

Rising energy costs and increasing concern about the ecological impact of chemical fertilizers have encouraged a renewed search for alternatives to fertilizer use:

- Animal manure and organic wastes are important sources of plant nutrients; they also improve the structure of soil and its ability to retain water. There are economic and practical limits to expanding their use, however. Replacing the chemical fertilizer now in use with animal manure would require a threefold increase in the world's animal population.

- Biological nitrogen fixation through microorganisms has traditionally been achieved by introducing legumes into crop rotations. Chinese and Vietnamese farmers have long grown the water fern Azolla in rice fields; it provides a habitat for blue-green algae that help supply the rice with nitrogen. Research into these and other nitrogen-fixing microorganisms is being undertaken (see Box 6.4), but in the short and medium term it is unlikely that they will significantly reduce the use of fertilizer.

- Mycorrhizas are fungi that live in contact with plant roots and transmit nutrients to them. Promising results have been achieved in laboratories, but large-scale applications are still some way off.

Chemical fertilizer will therefore remain a major and expanding source of productivity growth in developing countries. There is considerable scope for more efficient usage, in part through the development of new varieties of high-yielding crops that respond even more favorably to fertilizer than do present varieties; the development of rain-fed crops that respond better to fertilizer is also a possibility. The fertilizer industry has responded rapidly to increased demand; despite higher energy costs, ample raw materials exist for the industry’s future growth. The most likely constraints on increased fertilizer use in the developing world are shortages of seed and irrigation, and inappropriate government distribution and pricing policies.

**Research**

The emergence of genetic science in the mid-nineteenth century and the establishment of publicly financed agricultural research centers have fostered the scientific breeding and selection of agricultural products. Plant selection and improvement takes place today in hundreds of national and international centers forming a worldwide network that shares data, planting materials, and results and scours the earth for wild plants that might possess useful characteristics. At the frontier of genetic research, microbiologists are applying still more advanced
technology to develop new or dramatically modified plants (Box 6.4).

Until recently, tropical agricultural research was concentrated on export crops such as sugar, bananas, rubber, cotton, tea, coffee, and oil palms. Major progress in cereals was confined to temperate areas until the early 1960s, when major breakthroughs were made in tropical wheat and rice technology. International research centers played a key role in developing and disseminating this new technology (Box 6.5).

Tropical research on sorghum, millet, and maize started later and advanced more slowly. Outside the tropics, these cereals had been used primarily as animal feed and their taste was inferior; there was little incentive to improve them in tropical areas. Similarly, very little research had been done on pulses (such as chickpeas and cowpeas) and root crops such as cassava, because these were not grown in temperate areas. Whether modern scientific techniques and a high international and national research priority can make up this lost ground remains to be seen.

If the answer is positive, advances in those crops could have a major impact on reducing poverty (see Chapter 7). In sub-Saharan Africa, pulses, roots, and tubers account for 27 percent of agricultural output; by comparison, cereals represent only 17 percent of production. In South and Southeast Asia and China, in contrast, the figures are 9 to 10 percent and 40 to 50 percent, respectively.

Plant breeding in the tropics is complicated by wide local variations within seemingly homogeneous natural conditions, and by the way local varieties have been bred to survive under those conditions rather than to achieve

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**Box 6.5 The international agricultural research centers**

The worldwide system of internationally funded research centers grew out of a crop investment program jointly sponsored by Mexico's Department of Agriculture and the Rockefeller Foundation. In 1943, a team of Mexican and US scientists began a systematic effort to develop improved varieties of maize and wheat. Encouraged by the success of this venture, the Rockefeller and Ford Foundations joined forces in the first truly international agricultural research center, the International Rice Research Institute (IRRI), established in the Philippines in 1960. The Mexican crop programs were reconstituted in 1966 on the IRRI model as the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT).

The Consultative Group on International Research (CGIAR) was established in 1971 as an informal association of countries, multilateral organizations, and private foundations. Its main purpose is to support and expand research which will help solve agricultural problems common to many developing countries and improve food production in the developing world. In addition to the chairman and secretariat, provided by the World Bank, CGIAR has an advisory panel, the Technical Advisory Committee (TAC), whose secretariat is financed jointly by UNDP, the World Bank, and FAO. TAC is made up of thirteen distinguished agricultural and social scientists, drawn about equally from developed and developing countries.

CGIAR supports mainly research and training programs to enhance the production and yield stability of food crops cultivated throughout the developing world. The group also sponsors research on livestock production systems and diseases, the conservation and utilization of plant genetic resources, and food policy. Finally, CGIAR helps countries strengthen their national agricultural research systems.

Thirteen international centers and programs are currently funded through CGIAR. Among the newer centers, the International Institute of Tropical Agriculture (IITA), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and the International Center for Agricultural Research in the Dry Areas (ICARDA) are involved in crop research, while the International Livestock Center for Africa (ILCA) and the International Laboratory for Research on Animal Diseases (ILRAD) concentrate on livestock issues. All these centers devote most of their resources to work on such important crops as sorghum, millet, cassava, and legumes, and on improvements in the farming systems, including livestock farming, in which they are produced. Their intent is to develop better varieties and farming systems for resource-poor farmers in the rain-fed areas—a group hitherto unable to benefit from modern rice and wheat technologies. Improving production in the rainfed tropics is a slow and difficult process, and it is hard to predict the timing of significant increases in yields. National agricultural research programs are also often weak in these areas; the international centers thus currently provide much of the research momentum required to fill the large gaps in technology development.

The impact of the international agricultural research system is not confined to new technology. It has also provided leadership in research philosophy and methodology, which is changing the way research is conducted in developing countries and has demonstrated to policymakers that investment in high-quality agricultural research pays off.

Funding for the international programs increased sixfold between 1972 and 1980. In the last two years donor contributions have grown relatively slowly, however, to a total of US$150 million. Limited increases in funding, combined with exchange rate changes and high rates of inflation, have caused most centers to cut back their activities at a time when the need and demand for their services are increasing rapidly.
higher yields. To replace existing seeds with higher-yielding ones, new varieties may need to be developed for each small region. To survive, plants also need to build up resistance to local pests and diseases. Varieties of wheat and, to a lesser extent, rice have been developed that can be adapted to many different conditions; other grains are less adaptable. A variety of maize may produce high yields in one valley in the highlands of Mexico, and only a minimal harvest in a neighboring valley, and it may fail completely in central India.

Most traditional cereal strains have been adapted to soils that are short of nutrients. The stem and the leaves, rather than the edible head, use most of the nutrients. When fertilized, growth is largely in the stem and may result in "lodging" (the plant's falling over in wind and rain). Plant breeding in the last three decades has therefore concentrated on developing shorter, sturdier cereal plants whose heads make up a higher percentage of their total weight. The resulting shorter-stemmed plant can support the larger head which nutrients promote. Yields are only one concern of plant breeders: others include growing time, resistance to pests and disease, flavor, and storage qualities.

Despite the proven value of research, developing countries are not yet devoting enough resources to it. A recent study showed that spending on research in fifty-one developing countries had risen significantly over the past decade but was still equivalent to only 0.5 percent of the value of agricultural output in 1980. This is much less than developing countries' spending on agricultural extension services. By contrast, although industrial economies spend about 1 to 2 percent of the value of their agricultural output on research, this represents about four times their expenditure on extension. Given the very high returns to agricultural research, a strong case can be made for investing more in research in developing countries.

The role of international research centers is changing as national systems are built up and take over more of the task of developing new technology. Today, special emphasis is given to training national research workers, and the centers are increasingly functioning as clearinghouses for highly specialized knowledge and genetic material. The centers have also become more involved in developing research methodology, especially for analyzing social and economic obstacles to progress at the individual farm level.

Some small countries and those that lack skilled manpower and cannot afford basic research have special problems. They have to rely more heavily than others on practices and materials developed by the international centers, while devoting most of their own efforts to applied research at experimental stations and on farms. There is considerable scope for broadening regional cooperation in areas such as Central America and sub-Saharan Africa. Unfortunately, most past attempts at regional cooperation have not been very successful.

**The Green Revolution**

Within little more than a decade, over half the developing world's wheat acreage and one-third of its paddy fields were converted to new high-yielding, semi-dwarf varieties. With good irrigation and the right amount of fertilizers and chemicals, their yields can be two to three times those of traditional varieties (see Box 6.6).

This dramatic change has been labeled the Green Revolution. It began in the mid-1960s with the release of new varieties of wheat from CIMMYT in Mexico, and of rice from IRRI in the Philippines. The new wheat varieties were introduced to Pakistan and India in 1966. Wheat production in India had doubled by 1970–72 to 23.4 million tons. At that point, the plants were affected by a disease known as rust and production stagnated. By the mid-1970s, Indian scientists had developed varieties that not only resisted rust but also matured earlier. Seeds were also being distributed more widely. Production again started to increase, reaching 33 million tons in 1978–80. From being the world's second largest cereal importer in 1966, India had become self-sufficient by the late 1970s.

The new wheat varieties were quickly adopted in many parts of the world. China, Pakistan, and Turkey, among others, achieved significant increases in yields and production. Bangladesh, where wheat was once almost unknown, produced 1.2 million tons by 1980–81.

The first new rice varieties grew best during the dry season under clear skies; they were quickly adopted by the farmers in South and Southeast Asia who could irrigate during the dry season. A couple of years later, the varieties suitable for the monsoon season were released, but they were adopted relatively slowly and selectively because the semi-dwarf plants need reliable supplies of water during the growing season, and cannot be grown in heavily flooded areas. Relatively few paddy farmers in Asia enjoy this degree of control over their water supply. Where favorable conditions exist, however, the short maturity time of the new varieties has permitted double- or even tri-
Box 6.6 The Green Revolution in Punjab, India

The Indian state of Punjab, on the semi-arid, drought-prone Indo-Gangetic Plain, emerged from the colonial era with extensive irrigation infrastructure and good transportation facilities. Its farming community was prosperous and progressive, but used almost no cash inputs except canal water. Wheat, the most important crop, was grown on 30 percent of the farmland.

In the 1950s and early 1960s, Punjabi farmers began the transformation from traditional to commercial agriculture. They started to apply small amounts of fertilizer to their fields and output rose steadily.

In 1966 the first high-yielding wheat variety, which responded well to fertilizer and irrigation, was released. This innovation unleashed a chain of events that transformed Punjabi agriculture. Farmers quickly realized that it could double their yields. By 1969, they had planted more than two-thirds of their wheat fields with high-yielding varieties; average yields rose to 2.2 tons a hectare compared with 1.4 tons in 1966.

By 1972, just six years after the introduction of the new variety:

- Farm incomes had doubled, and savings had grown still faster.
- Savings were mainly invested in productive assets. The number of private tubewells and tractors increased sixfold and fourfold, respectively.
- The new wheat proved so profitable that some lower-value crops were replaced. With newly available wellwater, land that had previously lain fallow in the dry season could be cultivated. The wheat-growing area increased by 50 percent.
- Fertilizer use increased sixfold.
- Having done so well with wheat, farmers eagerly planted other high-yielding crop varieties and increased their use of inputs in the early 1970s.

Wheat production failed to rise further in the early 1970s, partly because of disease. Growth resumed after the introduction of disease-resistant varieties in the mid-1970s. By then, other crops had taken over wheat's role as growth leaders. Rice, potatoes, and other nontraditional crops expanded rapidly in both area and yield.

Larger farmers were the first to adopt the new technology, but small farmers and tenants soon took it up. Modern farming practices are now used throughout Punjab. As part of the commercialization of agriculture, crop sharing arrangements for tenants are gradually being replaced by fixed cash rents. With the expansion of farm income, small industry and service establishments have flourished. Many landless farm workers have moved into nonfarm jobs. Income per capita has been growing at an average rate of 3 to 3.5 percent a year for two decades.

A number of factors have contributed to the Punjabi success. The extensive existing canal system and the good groundwater resources, both of which could be exploited at a relatively modest cost, were of special importance. Prices were maintained at levels that gave farmers ample incentives to adopt new practices. Government investment in roads, markets, rural electrification, and other supporting infrastructure enabled farmers to take advantage of new opportunities. Finally, local research led to continuing improvements in varieties of wheat, rice, potatoes, cotton, and other crops.

There have been no such revolutionary gains in maize and sorghum, though some progress has been made. As noted earlier, tropical and subtropical maize varieties have been adapted to the particular circumstances of quite small regions. Many breeding stations have produced dramatically improved hybrids and composites, but attempts to grow them in other places have not succeeded. Improved maize varieties have been most widely adopted in Argentina, China, Kenya, and Zimbabwe.

Hybrid sorghums for human consumption were first made available in India in 1964, but it took twelve years to produce them in bulk, to develop their resistance to disease, and to overcome people’s reluctance to eat them. Some 4.5 million hectares, one-third of the rain-fed area, are now planted with these hybrids. They also spread in northeastern China in the mid-1960s. In Latin America, hybrid sorghum is chiefly grown for cattle feed on large commercial farms. Improved millets have not been widely adopted by farmers, and few improvements have been made in le-
gumes although active research is under way on these crops.

The results of the development of new grain varieties have been remarkable. In developing countries, cereal yields rose by 2 percent a year between 1961 and 1980: in the case of wheat varieties by 2.7 percent; in sorghum by 2.4 percent; and in maize by 2 percent (see Figure 6.8). Although rice yields increased by only 1.6 percent a year in developing countries as a whole, they rose by more than 3 percent a year in the Philippines and Indonesia, which were best suited to the new varieties.

The Green Revolution has transformed the lives of millions of farmers. It has failed to benefit a much larger number for some or all of the following reasons:

- The technology did not fit their climate and soil.
- National research systems were not available to adapt the international varieties to local conditions.
- Adequate rainfall, irrigation, or flood control was not available.
- Transport and marketing networks were deficient.
- Prices and other incentives were inadequate.

Progress in other tropical crops

The emphasis given to cereals in the developing countries reflects the critical importance of basic foods. Nonetheless, tree crops and nonfood crops are important exports in many developing countries. Moreover, tree crops are frequently grown on land not suited for the cultivation of annual crops. Fruits, vegetables, and vegetable oils are also becoming more significant as incomes rise. Their elasticity of demand in developing countries ranges from 0.5 to 0.9, which means that at median income levels demand for them grows twice as fast as it does for cereals, pulses, and root crops.

Developing countries account for 95 to 100 percent of the output and export of bananas, tea, coffee, cocoa, and rubber and between 45 and 60 percent of cotton, tea, tobacco, and sugar. In the case of coconuts, over 80 percent come from Asia. Palm oil is produced exclusively in developing countries, though the distribution of production among them has changed greatly. In 1965, 74 percent of output was in Africa, 23 percent in Asia, and 3 percent in Latin America. By 1980, almost 68 percent was produced in Asia, 28 percent in Africa, and 4 percent in Latin America. Although nonfood crops account for a small fraction of the agricultural output of the developing world as a whole, they represent as much as 20 to 35 percent of production in some countries: examples include Colombia, Costa Rica, Ghana, Guatemala, Liberia, Malaysia, Mali, Nicaragua, and Sri Lanka. Exceptionally—for example, in El Salvador and Ivory Coast—they can rise to 40 to 50 percent.

Unlike research on tropical food crops, research on tree crops and sugar has nearly as long and successful a history as that of temperate crops, largely because of the colonial interest in them as exports to developed countries. In several instances, notably sugar, palm oil, rubber, and coconuts, Green Revolutions as significant as those in wheat and rice have taken place, often more than once. Less spectacular but significant improvements in cultivation, fertilization, and harvesting techniques have also been made.

Production and productivity have improved much more rapidly than the growth of demand. Most tree crops have been exported mainly to the developed countries, where incomes and consumption are high and further income increases generate only limited extra demand for tree crops. Industrial substitutes also limit market demand for some crops such as rubber, cotton, and jute. Against these demand constraints, sizable productivity gains have helped reduce costs and prices. The general pattern of demand appears to be improving, as oil exporters and many middle-income countries increase their imports as incomes rise. In addition, higher petroleum prices have shifted the competitive balance somewhat from synthetics back to natural fibers.

Despite the drawbacks of tree crops, acreage for them can be expanded quickly and the technology is already well established. This makes them especially attractive in regions where progress on food crops is slow, particularly sub-Saharan Africa. There, the choice between food and nonfood production is not simple: both need to progress. Over the longer term, the need for local research on food crop improvements is
clear. In developing improved technologies for crops, however, choices need to be made on the basis of comparative advantage.

Supports for agricultural growth

Land improvement, new farming methods, and more research are all necessary requirements for agricultural growth, but they are not sufficient conditions for its attainment. Numerous complementary services are also needed if farmers are to translate the potential of science into the reality of bigger and better crops. The final section of this chapter examines what this back-up effort involves.

Infrastructure

The existence and expansion of basic infrastructure has contributed significantly to increased agricultural output in Asia and Latin America. For example, the Philippines has allocated about 5 percent of agricultural development spending to rural electrification programs, which now serve about 70 percent of the population. On a simpler level, basic roads are essential for getting agriculture moving. In many parts of Africa, farmers are more than a day’s walk from the nearest road. Measures to raise their production without transport and communications are of little use, because their crops cannot reach a market and they are cut off from new technology, inputs, and ideas.

Improved access usually brings with it an expansion of nonfarm enterprises such as shops, repair services, and grain mills. It also helps change customs, attitudes, and values. For example, a World Bank study of the impact of rural roads in the state of Yucatan in Mexico found that the roads offered an opportunity for enlarging women’s role by introducing new ideas, education, medical care, and economic alternatives to maize cultivation. In particular, women married later, had fewer children, and pursued more non-domestic activities.

Feeder roads are often neglected if left to national road transport authorities, which generally prefer the challenge of building major highways. Feeder roads may receive more attention if the responsibility for their planning, construction, and maintenance is devolved to local government or to area development authorities. This requires central government’s willingness to expand the revenue-raising powers of local government.

Externally financed projects have been successful in demonstrating that feeder roads can be built quite cheaply. Good examples are the World Bank’s first three rural development projects in the northern savannah areas of Nigeria, where 1,700 kilometers of feeder roads were built or improved between 1975 and 1980; and the much smaller cocoa and coffee development project in Togo, in which 200 kilometers of roads linking villages in mountainous terrain were built at less than half the cost tendered by private contractors. In both cases, local artisans were used to do much of the skilled work such as bridge and culvert construction.

When rural infrastructure is being improved, giving priority to simple tracks and spot improvements of roads for motorized vehicles enlarges the percentage of rural poor offered opportunities for productive activities by both private and public construction agencies (see Chapter 7). To derive full benefits from investment in roads, improvements often need to be complemented by easier access to credit for the purchase of motorized or nonmotorized vehicles. In addition, transport regulations often hinder the development of rural transportation.

Improving telecommunications has fallen prey to the artificial barrier between the "modern" and "rural" sectors. Telecommunications are not exclusively an urban tool. Agricultural growth can be accelerated if farmers have accurate market information and a fast way of calling for the repair of equipment and delivery of supplies. Rural industry is often an early beneficiary of an effective telephone network.

Extension

The adoption of new technology depends on the knowledge, skill, and motivation of farmers, together with a host of other factors which influence the farmers’ capacity to achieve output levels approaching those obtained on research stations (Box 6.7). The main task of agricultural extension is to transmit knowledge of better production methods to farmers, and to help them overcome difficulties in employing them. With some important exceptions, the performance of extension services has been disappointing.

The existence of a profitable technology is a precondition for successful extension work. In sub-Saharan Africa (and indeed in many other rain-fed areas), farmers ignore the advice of extension workers on planting dates and cropping when it does not suit their circumstances or promises little obvious reward. Instead, they continue to intercrop and spread out plantings to reduce risk and stretch their limited resources. In this and many other cases, the fault lies with a lack of applied research that takes account of local social and economic conditions (Box 6.8).
Box 6.7 The yield gap and agricultural extension services

Farmers in developing countries rarely achieve the record yields attained in developed countries or in controlled research. Most of this gap in yields is a result of commonsense decisions by farmers or of circumstances outside their control, rather than lack of skill or initiative on their part. In some cases, it may not pay farmers to buy inputs that might help improve yields. In others, the poor quality of the land or a lack of resources may make it impossible for them to use the cultivation practices that maximize yields. The figure illustrates some of the factors that cause yields at research stations and in farmers' fields to differ.

First, the technical ceiling for on-farm yields is lower than that for research stations. The latter use technologies that are not feasible at the farmers' usual scale of production. Research stations are usually located on choice land and can depend on irrigation if it is needed. The farmers' environment is rarely as kindly.

Second, the on-farm economic ceiling is often much lower than the on-farm technical ceiling. Farmers' profits are often highest at input levels lower than those necessary for maximum yields, because of diminishing returns on investment in inputs.

Third, farmers' actual yields are usually below even economic ceilings. This may be because key inputs such as fertilizer, water, and labor are not available when needed, or because volatile output prices and unreliable rainfall reduce expected returns. These factors may force the farmer into a "safety-first" strategy.

Farmers may also not know about optimal combinations of inputs or the best cultivation practices.

The relative magnitude of each part of the yield gap profoundly affects development strategy. Closing a large gap between the different technical ceilings imposed by on-farm and research environments requires either investment—for example, in flood control, land development, or irrigation—or research to develop crop varieties and farming practices better suited to on-farm conditions. A large gap between on-farm technical and economic ceilings calls for a review of price policies and improved market access for farmers. If actual yields are far below even the economic ceiling, solutions might include strengthening agricultural extension or advisory services, streamlining input supply and credit systems, or creating a crop insurance scheme.

Thus, extension services can help narrow the yield gap but cannot close it. Worldwide experience indicates that agricultural extension services are most effective when:

- They support a profitable, risk-free or low-risk technology that is unknown to farmers.
- Key inputs such as fertilizer and quality seed are available at the right time.
- Farmers have ready access to markets for their additional produce.

In particular, extension services are often biased toward work with men and neglect the very important role of women as farmers in most parts of the world. In some societies women carry out all but the initial land clearing and heavy plowing. In many still largely traditional farming systems women have exclusive responsibility for the cultivation of food crops. In these situations, no effort to improve productivity can succeed except by the direct involvement of women in the programs.

Other problems with extension reflect an inability of the farmers to respond because input supplies, marketing systems, and other supporting elements are inadequate. Extension is usually most effective when these necessary complements are present.

The rising burden of the recurrent costs of extension services is another limitation on both the growth in coverage and the full utilization of the services. Partially in response to problems of cost, and partially to provide a supplementary communication channel (particularly for women), a number of countries have explored the use of radio and other mass media to deliver extension messages. These experiences have demonstrated the potential for carrying agricultural information inexpensively to large audiences.
The extent to which radio can induce farmers to adopt sound new technical packages remains, however, to be fully assessed.

In recent years efforts have been made to improve the administrative efficiency and field-level effectiveness of several extension services and to develop better linkages both to the farmers themselves and to research. This is one of the key features of the Training and Visit System, originally supported by the World Bank in India and adapted to conditions in other countries.

The private sector also plays an important role in the diffusion of technology and advice to farmers. Machinery manufacturers, seed companies, and suppliers of fertilizer and pesticides must all reduce the cost of growing cotton and secure their staple food.

- Gambian groundnut farmers plant late so as not to compete for labor in millet growing. Although a late crop needs more labor for weeding, there are fewer alternative productive uses of labor at this relatively slack time of year.
- In Nigeria, a crop mixture gave 60 percent higher gross returns per hectare than pure stands. It also improved returns on labor in peak periods by more than 25 percent, despite higher overall labor input.
- African farmers in these three countries, despite their limited resources and output, make production decisions in much the same way as larger operators. They respond rapidly to changing resource availability, constraints, and incentives and balance available resources to meet multiple (often conflicting) objectives. In fact, considerations which might be of only minor significance on large farms often assume great importance on small ones, owing to resource limitations and the close interrelationships between farm and household decisions.

Marketing

Crop marketing activities are often the key to opening up subsistence agriculture. Supplying urban consumers with food, exploiting foreign trade opportunities, specializing according to the comparative advantage of each region, village, and farm—these can take place only if there are intermediaries equipped to finance, buy, sell, transport, process, and store farmers’ products and to distribute purchased inputs at the time they are needed. There is a tendency to take these activities for granted. In most tropical developing countries they take place under difficult physical conditions, especially for crop transport and storage, and often in an adverse policy environment. This makes life harder for farmers who want to enter the market.

Despite these problems, farmers in the developing world have generally responded eagerly to market opportunities. Smallholder farmers rapidly adopted the growing of rubber trees in Malaysia and of cocoa, groundnuts, and cotton in West Africa once marketing channels were established in the late nineteenth century.

Cocoa, a difficult plant to nurture, had never before been grown by African farmers. Yet in little more than a half century, or only two generations, West Africa’s production of cocoa beans reached over 1 million tons a year; it captured 70 percent of the world market and brought farmers more cash per day’s work than any other crop ever grown there. More recently, in the Ivory Coast, cocoa production increased from 80,000 to over 400,000 tons in the two decades since 1960, largely because of fair prices and marketing.

Marketing has many facets, as a brief review of World Bank work reveals. In Mexico, under PIDER III, project finance is being used to organize small farmers into associations linked to a central distribution agency; to build local storage facilities; to build and improve retail stores; to develop rural markets; and to conduct a consumer information program through the home extension service. Under the Piaui project in...
Brazil, a ten-component marketing program is aimed at bringing together poor producers and consumers. In Cameroon, the ZAPI project includes support for a rural distribution network for agricultural supplies, an urban market to handle surplus crops from rural areas, and the improvement of processing and marketing facilities for the export of coffee and cocoa. In the Philippines, the land settlement program is concerned with developing markets for new plantation crops. In Greece, over 6,000 small vegetable farmers have been linked by local marketing corporations to supermarket outlets for their produce in western Europe, as part of a Bank-financed project supporting intensive production of winter vegetables (Box 6.9).

Marketing can be handled by the public or private sector or a mixture of the two, depending on the circumstances of individual countries. Because of its political and economic sensitivity, it has often been a public monopoly.

Although the reasons for intervention were sometimes valid at the time public marketing agencies were created, often during or shortly after the colonial period in Africa and Asia, a high price is being paid to keep some of them in place. Serious inefficiencies have characterized the operation of many parastatal marketing agencies. Some arise from problems found in almost all parastatals—overmanning, inadequate nonsalary budgets, and the scarcity of good managers. Sometimes official producer prices and consumer prices for food crops are fixed by governments with little regard to the actual costs of collection and distribution, frequently on a uniform national basis. Then the agencies are left to buy, collect, and deliver in the most distant and costly regions, and they are not always fully reimbursed for losses incurred in the process.

In food-crop marketing, there are usually parallel marketing channels; the legal and official marketing agency coexists with an often semiclandestine private trading sector. Some governments do not put much trust in the private sector’s ability to provide stable supplies of food to urban markets, even when private traders handle the bulk of the trade. In such cases, private intermediaries are tolerated as indispensable partners, but the economic environment does not enable them to operate efficiently. The uncertainties associated with the ambiguous position of private trade and traders discourage full-time involvement in food marketing, investment in transport and storage, and a systematic approach to developing an adequate supply network. This is starting to change, as governments recognize the value of involving private traders.

State-owned agencies also frequently monopolize the supply of inputs. They often fail to buy and distribute seed, fertilizer, and

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**Box 6.9 Productivity and small farms: Intensive vegetable production in southern Greece**

As the agricultural labor force moves rapidly into the nonfarm economy, farming in Greece is under pressure to increase labor productivity. Small and fragmented landholdings in southern Greece limit opportunities for mechanization. One promising alternative has been to develop high-value cropping systems to supply European fruit and vegetable markets.

Over 6,000 small vegetable farmers in the region are currently participating in a program which provides them with equipment to promote more intensive cultivation, and helps them sell their output in the profitable markets of western Europe. The program, which is supported by a World Bank loan, is expected eventually to raise the productivity and incomes of 9,000 small-farming families.

The key investment is a small greenhouse covered with a single layer of clear plastic and equipped with irrigation and ventilation. Winter heating is expensive, however. The new program therefore includes research on heat conservation, use of solar energy for heating, screening of cold-resistant vegetable varieties, and manipulation of their planting dates.

The program is also helping to sell Greek vegetables more efficiently in export markets. Traditionally, vegetable exporters handle volumes of produce which are too small to support the cost of adequate grading and packaging facilities. They also tend to have inadequate market representation and information, and to supply a single product only, often to a single market.

Greek exporters (and the small farmers who supply them) have thus been unable to supply the western European supermarket business, which is highly concentrated and represents almost 75 percent of the fresh fruit and vegetable market. Breaking into this market, which relies on direct contracts incorporating predefined quality standards and fixed delivery schedules, requires improvements in the coordination and planning of exports.

To ensure that investment in more intensive vegetable farming equipment and methods will pay off in export sales, four marketing companies, to be owned mainly by farmers, cooperatives, and private exporters, are being established. The companies will coordinate small farmers’ output under production and delivery contracts, operate grading and handling facilities, and provide a reliable and timely supply of quality products to supermarket chains in Europe. In this way, Greek vegetable farmers will benefit from expanding and assured markets and better prices, despite the small average size of their holdings.
pesticides at the time farmers need them because funds are not yet available from the national budget. For some inputs such as pesticides and herbicides more countries could replicate the success of Bangladesh and the Republic of Korea in getting agro-chemical manufacturing companies to participate and invest not only in the importation and wholesale distribution of their products, but also in local adaptive research, field trials, and demonstrations to farmers.

The production and distribution of quality seed is another field with broad possibilities for private sector participation. Seed companies in particular often work closely with government agencies in distribution and marketing.

Box 6.10 The Indian seed industry

Getting quality seeds to 70 million farmers on time is a challenge, but the Indian seed industry is rising to it. Since its infancy two decades ago the industry has grown enormously. It now comprises one national corporation, a dozen state-owned seed corporations, and some 300 private companies. The process of growth has been neither smooth nor easy. India's experience illustrates some problems faced by both the private and public sectors when agriculture undergoes rapid transformation.

Before the Green Revolution, most farmers reserved part of their crop for the next year's seed. Occasionally they obtained new seed, grown and distributed by state agricultural departments. A few private companies produced vegetable and flower seeds.

Following the release of the first hybrid maize varieties in 1961, India's agricultural planners realized that the seed industry needed to be strengthened. The National Seeds Corporation was formed in 1963 and started to grow foundation seed. The creation of private seed companies was encouraged, and a number of them were given the opportunity to buy imported seed-processing equipment on a hire-purchase basis.

By the mid-1960s, hybrid and high-yielding seed varieties had been released for a wide range of crops. Demand for quality seed took off. Because the private seed industry was still embryonic, public sector seed multiplication was stepped up through state and local governments and agricultural departments; state seed corporations were established.

Swept along by fast growth, the public seed production system became overextended. Quality declined, and financial losses were incurred. Private companies began to have serious misgivings about their future in the Indian seed industry.

In 1975, the state of Maharashtra authorized a few seed companies to produce their own foundation seed. This decision has done much to ease the supply of high-quality foundation and certified seed, and to ensure a steady flow to farmers. It has also speeded up the development and popularization of new varieties.

Only recently have dealers, distributors, and farmers become accustomed to the idea of seed marketed through seed companies. Initially, the companies tried to promote their products by demonstrations on farms; private retailers and cooperatives were encouraged through consignment arrangements, which left ownership of any unsold seed with the seed companies.

Today, seed is being distributed in India by a network of more than 10,000 seed dealers throughout the country. Farmers have become quality-conscious and have developed preferences for brands of demonstrated quality.

As private seed enterprises have prospered, they have become committed to genetic research and have developed their own improved hybrids of sorghum, millet, cotton, maize, and some vegetables. The search for new varieties has been extended to other crops such as sunflower, safflower, and pigeon peas. The industry is an important example of constructive, competitive interaction between the public and private sectors.

Hybrid seeds need to be replaced every year, so an active and widespread distribution chain is essential. The Kenya Seed Company, a mixed enterprise, has sold its Kitale maize hybrid through village shops and has successfully distributed seed to farms of every size in the Kenya Highlands. In ecologically similar areas of neighboring countries, the absence of such a marketing system has meant that the diffusion of maize hybrids is minimal. India's seed program also combines the efforts of the National Seed Corporation, state seed companies, and private companies (Box 6.10).

Credit

Credit is essential for modernization, growth, and equity. Larger farmers are generally able to obtain loans under government credit schemes and from agricultural banks, but small farmers find access to these institutions difficult and rely mostly on informal credit sources. Because the costs and risks of unsecured loans to small farmers are high, local moneylenders often charge much higher interest rates than official credit schemes.

In an attempt to remedy this imbalance, many countries have introduced credit schemes for small farmers. Their record is mixed. Credit often still goes to large farmers or is diverted for nonagricultural purposes. To improve the performance of agricultural credit schemes, certain lessons seem clear:

- Early establishment of rules for repayment (with clearly understood waivers in the event of crop failure) will not only safeguard the financial viability of the lending agency but also help spur farmers to greater efficiency.
- Improved access to credit is of more benefit to small farmers than subsidized interest rates,
since the latter in effect ration the amount of credit available. If more farmers are to be served, interest rates and other charges should reflect the true costs of lending and credit recovery. There is sometimes scope for accepting assets such as animals as security for loans.

• Formal credit agencies have overemphasized lending and neglected the provision of other financial services. Rural savings schemes are particularly useful for expanding the financial base of lending and for encouraging repayment. There is considerable evidence that small farmers do save when offered attractive savings rates.

• To promote loans and savings, agricultural banks could make much more use of rural agencies already in the field. They could also develop closer links with cooperative and group-farmer schemes, as has been done in Malawi, for example.