Agricultural R&D in the Developing World

Agricultural R&D in the Developing World: Too Little, Too Late?

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Dedicated to Derek Edward Tribe, 1926–2003,
who, as the first executive director of Australia's Crawford Fund,
believed passionately in and worked tirelessly for
the support of international agricultural research.

We still have not developed a set of successful public programs for investing in agricultural research and technology in poor countries . . . the investment in general is woefully inadequate both in the manner in which it is being accomplished and in the amounts spent for this purpose.

—Theodore W. Schultz, What ails world agriculture? *Bulletin of the Atomic Scientists,* January 1968. Reprinted in V. W. Ruttan, A. D. Waldo, and J. P. Houck, *Agricultural policy in an affluent society.* New York: W. W. Norton and Company, 1969, pp. 299–300.

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Foreword

This book was conceived as a companion to the 1999 volume *Paying for Agricultural Productivity,* published by Johns Hopkins University Press in conjunction with IFPRI. That volume dealt with investments, institutions, and policy processes regarding agricultural R&D in developed countries. This book addresses the same set of issues for the developing countries, and the relationship of those countries to the richer parts of the world where the preponderance of agricultural innovation still takes place. It also reviews developments within the Consultative Group on International Agricultural Research (CGIAR), along with the changing roles of international research generally, in light of the substantial shifts in science funding and policy (as well as in the science itself) that are taking place throughout the world.

The book combines new evidence with economic theory and an economic way of thinking about science policy—highlighting the developing-country aspects—as well as a set of in-depth, comparative country studies. These country studies take us well beyond generalities, providing insights into the important changes taking place within these countries and others they represent. The countries covered include the largest developing countries—China and India—as well as a range of richer and poorer, and more- and less-developed countries, representing most parts of the globe.

The evidence and ideas presented in the book are disquieting. Over the past several decades, at least, spillovers of agricultural technology from rich countries to poor countries demonstrably increased productivity and food security for many parts of the developing world. As the authors document, however, recent developments in both the developed and developing worlds mean that poor countries may no longer be able to depend as they have in the past on spillovers of new agricultural technologies and knowledge from richer countries, especially advances related to enhanced productivity of staple foods.

As a consequence of these changes, simply maintaining their current agricultural R&D policies may leave many developing countries as agricultural technology orphans in the decades ahead. Developing countries may have to become more self-reliant and perhaps more dependent on one another for the collective benefits of agricultural R&D and technology. Some of the more advanced developing countries like South Korea, Brazil, China, and India seem to be gaining ground, with productive and self-sustaining local research sectors taking hold. However, other parts of the developing world, as illustrated in this book by reviews of agricultural R&D in Zambia, Bangladesh, and Indonesia, are merely regaining lost ground or slipping further behind. Aside from a handful of larger countries, many developing countries, especially in Africa, are facing serious funding and institutional constraints that inhibit the effectiveness of local R&D. Together, these factors may lead to serious food deficits.

The information assembled here and the lessons learned in this volume argue for refocusing attention on agricultural R&D as an instrument for long-run economic development to help avert a continuation of the chronic hunger and malnutrition that afflict all too many people around the world. These lessons will pay off if they help revitalize multinational engagement and investment in the global public benefits of international agricultural research.

Joachim von Braun
Director General, IFPRI

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The editors acknowledge with gratitude the outstanding assistance of Mary Jane Banks, Sue Pohlod, Louise Letnes, and the staff in the Communications Division at IFPRI who helped turn our chapter files into a coherent book manuscript. We also received extensive and excellent comments from Stanley Wood and two anonymous reviewers, and helpful guidance from IFPRI's Publication Review Committee. Finally, we owe a big debt of gratitude to the authors of the country chapters, who worked willingly with us through multiple rounds of revisions.

Chapter 1

Introduction and Overview

Julian M. Alston, Philip G. Pardey, and Roley R. Piggott

In the early 21st century, the science of agriculture has started to shift gears, just as it did 100 years ago. At the beginning of the 20th century, Charles Darwin's theory of evolution, the pure-line theory of Wilhelm Johannsen, and the rediscovery of Gregor Mendel's laws of heredity contributed to the rise of plant breeding, while Louis Pasteur's germ theory of disease and the development of vaccines opened up lines of research in the veterinary sciences. The next epoch in agricultural technology will also have fundamental biological science at its foundation. Today, scientists armed with new molecular biologies involving genomics, proteomics, recombinant DNA, and supporting informatics technologies are delving deeper into the genetics of life, with potentially profound and pervasive implications for agriculture worldwide.

The context in which that science will take place has evolved and shifted as well. The public purpose in agricultural R&D is less focused and more closely scrutinized than it was a century ago; the general public seems less trusting of some areas of science, and perhaps of some scientists (National Science Board 2002); and marked changes are taking place in the intellectual property regimes relating to the genetic resources used in agriculture and the technologies used to transform them (Boettiger et al. 2004; Pardey, Koo, and Nottenburg 2004). Complacency has crept in too. Some question the need for continued public funding at recent levels, suggesting that the world's food problems are being solved or constrained by things other than R&D, or that the private sector will do the job (see Runge et al. 2003). Others see a scientific apartheid taking shape, with large parts of the developing world being left behind or denied the prospects science has to offer for growth, development, and prosperity (Serageldin 2001).

The world's agricultural economy was transformed remarkably during the 20th century. The agricultural productivity growth that fueled this change was generated primarily by agricultural R&D financed and conducted by a small group of rich countries—especially the United States, but also Japan, Germany, and France. In an increasingly interdependent world, both rich and poor countries have depended on agricultural research conducted in the private and public laboratories of these few countries, even if they have not contributed to financing the activity.

But now the rich-country research agendas are shifting. In particular, they are no longer as interested in simple productivity enhancement. Dietary patterns and other priorities change as incomes increase. Food-security concerns are still pervasive among poor people, predominantly in poor countries. In rich countries we see a declining emphasis on enhancing the production of staple foods and an increasing emphasis on enhancing certain attributes of food (such as growing demand for processed and so-called functional foods) and on food production systems (such as organic farming, humane livestock production systems, localized food sources, and "fair trade" coffee). In addition to growing differences between rich and poor countries in consumer demand for innovation, research agendas may diverge because of differences in producer and processor demands. Farmers in rich countries are demanding high-technology inputs that often are not as relevant for subsistence agriculture (such as precision farming technology or other capital-intensive methods). As well as differences in value-adding processes to serve consumer demands, differences in farm production technologies are emerging to serve the evolving agribusiness demands for farm products with specific attributes for particular food, feed, energy, medical, or industrial applications.

As rich-country research responds to these changing patterns of demand, the emphasis of the science is shifting in ways that could undermine the international spillovers that contributed significant past gains in food production throughout poorer countries. These spillovers are not generally well understood, and their importance is underappreciated (Alston 2002).

Other aspects of agricultural science policy, and the context in which research is done, are changing as well. In particular, the rise of modern biotechnology and enhanced intellectual property rights (IPR) regimes mean that technologies that were once freely accessible will be less accessible in the future. Moreover, the new technologies may not be as portable as in the past. Biotech companies, which are mostly located in the rich countries—particularly in the United States—emphasize technologies that are applicable at home. These and other factors limit incentives for companies to develop technologies for less-developed countries (Bradford et al. 2004). Hence some fear that less-developed countries will become technological orphans, abandoned by their former private- and public-sector benefactors in rich countries (see, for example, Pinstrup-Andersen and Cohen 2001).

In *Paying for Agricultural Productivity,* Alston, Pardey, and Smith (1999) documented the changing institutions and investments in agricultural R&D in a selection of rich countries.[1] In many countries, toward the end of the 20th century public and private roles shifted, and support for public agricultural research slowed, especially for near-market, applied, productivity-enhancing research. Slower-growing, stagnant, or shrinking public agricultural research funds are increasingly being diverted toward environmental objectives, food quality and safety, and so on. Who, then, will do the research required to generate sustenance for a growing world population when—at least for another century—virtually all population growth will occur in the poorer parts of the world?

The purpose of this volume is to document the changing institutions and investments in agricultural R&D in less-developed countries, in part to form a companion volume to *Paying for Agricultural Productivity* by providing a more complete global picture of the issues. A more important purpose is to take stock of what is happening in less-developed countries. This task is especially compelling if, as seems likely, these countries will have to become more self-reliant in developing crucial new agricultural technologies.

In Chapter 2 we set the scene for the chapters that follow. We introduce some economic principles for government intervention in agricultural research, along with detailed data on the evolving patterns of agricultural research spending around the world. Chapters 3 through 11 cover nine countries, including the most important among the less-developed countries, in terms of total investment in agricultural R&D.[2] The case-study countries include a reasonable representation of countries from Asia, Latin America, and Africa. Some basic features of the economies of these countries (plus the United States for comparison), are summarized in Table 1.1, including measures of their overall size, structure, economic policies and performance, and institutional infrastructure; and measures of the key features of their agricultural sectors, such as primary products, agriculture's share of GDP and the workforce, and agroecological attributes.

The chapters document the history and current status of the national agricultural research systems (NARSs) in terms of policies, institutions, investments, and achievements. The case studies cover a geographically dispersed area (South Africa and China, for example) and diverse farming systems (such as Brazil vs. Korea), yet some common themes emerge.

In addition to these country-specific chapters, Chapter 12 addresses the collective multinational effort to provide agricultural R&D through international

Table 1.1 Profiles of case-study countries

Indicator	Bangladesh	Brazil	China	Colombia
Economy-wide indicators				
Population (2003, millions)	138.1	176.6	1,288.4	44.6
Urbanized (2003, percent of total population)	27	83	39	76
GDP (2003, billions)				
Current international dollars	244.4	1,375.8	6,446.0	298.8
Current U.S. dollars	51.9	492.3	1,417.0	78.7
GDP per capita (2003)				
Current international dollars	1,770	7,790	5,003	6,700
Current U.S. dollars	376	2,788	1,100	1,765
Growth in GDP per capita (1993–2003, percent per annum)	3.1	1.1	7.7	0.4
Trade shares, 2002				
Value of exports in GDP (percent)	14	15	29	20
Value of imports in GDP (percent)	19	13	26	21
Communications (per 1,000 people)				
Telephone mainlines, 2002	5	223	167	179
Mobile phones, 2003	10	264	215	141
Internet users, 2003	2	82	63	54
Road density, 1999 (km per km^2)	1.59	0.20	0.14	0.11
Percentage of roads paved, 1999	10	6	22	14
Economic freedom index, 2005	3.95	3.25	3.46	3.21
Ranking (out of 161)	141	90	112	88
Trade policy	5	4	4	4
Property rights	4	3	4	4
Corruption perceptions index, 2004	1.5	3.9	3.4	3.8
Corruption perceptions (ranking out of 145)	145	59	71	60
Agricultural indicators				
Agricultural value-added, 2001				
Current international dollars (bilions)	52.6	78.6	852.0	37.7
Percent of GDP	24	6	16	14
Population actively engaged in agriculture, 2004 (percent of total)	52	15	64	18
Top five agricultural products by value (average 2001–03, percent of total)	Rice 64 Beef and veal 4 Goat milk 3 Potatoes 3 Pimento 3	Beef and veal 22 Soybeans 13 Chicken meat 11 Sugarcane 8 Cow milk 8	Pig meat 17 Rice 10 Hen eggs 6 Maize 4 Wheat 4	Beef and veal 19 Cow milk 18 Chicken meat 9 Coffee 8 Sugarcane 7

India	Indonesia	South Africa	South Korea	Zambia	United States
1,064.4	214.7	45.8	47.9	10.4	290.8
28	44	59	84	40	78
3,078.0	721.5	474.1	861.0	9.1	10,923.4
600.6	208.3	159.9	605.3	4.3	10,948.6
2,892	3,361	10,352	17,975	875	37,563
564	970	3,491	12,637	413	37,650
4.3	1.6	0.7	4.4	–0.6	2.1
15	36	34	35	24	10
16	29	30	34	29	14
40	37	107	489	8	646
25	87	364	701	22	543
17	38	58	610	6	551
0.85	0.20	0.30	0.88	0.90	0.69
57	57	20	75	22	59
3.53	3.54	2.78	2.64	3.40	1.85
118	121	56	45	106	12
5	2	2	3	3	2
3	4	3	2	3	1
2.8	2.0	4.6	4.5	2.6	7.5
90	133	44	47	102	17
658.5	109.6	13.2	30.3	1.8	198.6
25	17	3	4	22	2
58	46	8	8	67	2
Rice 18	Rice 37	Beef and veal 16	Pig meat 17	Maize 15	Maize 17
Buffalo milk 11	Coconuts 6	Maize 14	Rice 15	Beef and veal 16	Beef and veal 16
Wheat 8	Palm oil 6	Chicken meat 12	Cow milk 7	Cassava 10	Cow milk 11
Cow milk 7	Maize 5	Cow milk 8	Hen eggs 6	Hen eggs 7	Chicken meat 10
Sugarcane 4	Cassava 4	Grapes 5	Beef and veal 6	Chicken meat 7	Soybeans 10

(*continued*)

Table 1.1 (continued)

Indicator	Bangladesh	Brazil	China	Colombia
Area of agricultural land (avg 1999–2001, thousand km²)	91	2,619	5,496	457
Percentage of total land area	70	31	59	44
Percentage of agricultural land irrigated	46.2	1.1	9.9	2
Percentage of agricultural land arable and permanently cropped	93.4	25	27.2	.6
Percentage of agricultural land permanently pastured	6.6	75	72.8	90.4
Agroecological attributes (percent of ag)				
Temperate				
Irrigated and mixed irrigated	0	0	18.8	0
Rainfed	0	0	35.3	0
Moderate cool tropics	0	15.0	38.7	30.9
Warm tropics and subtropics				
Irrigated and mixed irrigated	56.6	1.1	1.0	10.9
Sloped rainfed	2.0	18.0	1.7	22.0
Flat rainfed	41.4	65.9	4.5	36.1

Sources: Data for population (total and urbanized), GDP, GDP per capita, growth in GDP per capita, trade shares, telephone mainlines, mobile phones, Internet usage, road density, proportion of roads paved (except for China), and agricultural value-added are from World Bank 2005. Data for China's proportion of roads paved are from CIA 2005. Data for the economic freedom index are from Miles et al. 2005. Data for the corruption perception index are from Transparency International 2005. Data for population actively engaged in agriculture are from Table A.3 in FAO 2005a. Data for quantity of agricultural production by value are from FAO 2005b, weighted by commodity-specific international prices averaged over the 1989–91 period from unpublished FAO data files. Shares of agricultural area in total and in a given agroecology are calculated from data and digitized maps underlying Wood et al. 2000.

Notes: GDP per capita in current U.S. dollar units was calculated from respective GDP and population data in World Bank 2005. The growth in GDP per capita was calculated by taking the average of the difference in natural logs for GDP per capita (in constant

agricultural research centers, emphasizing the Consultative Group on International Agricultural Research (CGIAR) system. Chapter 13 presents a synthesis of the main themes and issues from the case studies, and directions for policy change to address these issues.

The Audience

This book has been written primarily for those who make policy and allocate resources for agricultural research and extension, and the policy analysts and development specialists who advise them: specifically, strategic decision makers and their advisers in international agencies, national governments, and public or private agricultural research and extension organizations. These decision makers must gauge

India	Indonesia	South Africa	South Korea	Zambia	United States
1,807	445	996	20	353	4,122
61	25	82	20	47	45
30.3	10.8	1.5	60	0	5.4
94	74.8	15.8	95	15	43.2
6	25.2	84.2	5	85	56.8
0	0	0	43.4	0	5.6
0	0	0	56.4	0	66.7
5.2	0.5	77.4	0.2	5.1	22.5
47.9	27.7	2.2	0	0	0.7
8.7	32.2	3.3	0	18.6	1.6
38.3	39.5	17.1	0	76.2	2.9

local currency units) over the years 1993 to 2003. The proportion of paved roads for China was calculated from respective data within CIA 2005. Internet usage figures for Brazil, South Africa, and the United States are 2002 (not 2003) data. The economic-freedom index ranges from 1 (most free) to 5 (most economically repressed); the general index is constructed from subratings based on trade policy, fiscal burden of government, government intervention in the economy, monetary policy, capital flows and foreign investment, banking system and finance, wages and prices, property rights, regulation, and informal market; the highest-ranking country is Hong Kong, with an index of 1.35. The corruption perceptions index ranges from 0 (highly corrupt) to 10 (highly clean); the highest-ranking country is Finland, with an index of 9.7. Agricultural land includes arable, permanently cropped, and permanently pastured land. International dollars are obtained by currency conversion using purchasing power parity (PPP) indexes, which compare prices across a broader range of goods and services than conventional exchange rates.

the adequacy and appropriateness of research activities for which they are responsible and build the new institutions for R&D that will facilitate sustained growth and development in the decades ahead. The information should also be of interest to students and scholars who seek to know what has happened in agricultural R&D and why, and to understand the consequences in ways that may lead to better-informed policy choices. Understanding the histories of public agricultural research institutions and the forces of change that confront each system, and learning from the changes made to address these external forces, will provide a basis for formulating public agricultural R&D policies that are both politically feasible and economically worthwhile. Beyond these primary audiences, the material in this book should also be accessible and of interest to farmers, food processors, wholesalers, retailers, environmentalists, scientists, and all who have a direct stake in, or are affected by, the agricultural research system, as well as those generally interested in development and development economics.

Notes

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1. See also Alston, Pardey, and Taylor (2001) and Pardey and Beintema (2001).

2. The most significant deficiency in country coverage is that we do not include any of the countries of the former Soviet Union.

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Chapter 2

Developing-Country Perspectives on Agricultural R&D: New Pressures for Self-Reliance?

Julian M. Alston and Philip G. Pardey

This chapter provides a conceptual and empirical context for the case studies in Chapters 3 through 12. First, we briefly discuss the nature of market failures in agricultural research—both among firms within a country, and among nations—and the roles for government intervention in general. Next, we consider the distinguishing features of less-developed countries and what they might imply for R&D policy. We also discuss the important role of agricultural R&D and technology spillovers among nations, and the past dependence of the world's poorest countries on their richer neighbors. Next, we document the longer-term global story of institutions and investments in agricultural R&D, emphasizing the great importance of past achievements in agriculture and recent changes that leave grounds for concern about the prospects for the next 20 years and beyond. In the light of these facts, we contemplate the prospects for the future and the implied need to reinvent international collective action in agricultural R&D and reinvest in the associated global public goods institutions.

The presentation of facts and ideas here is brief, in recognition of both space limitations and the availability of the more complete treatments upon which much of this discussion draws. The in-principle arguments about the economics of agricultural R&D policy are based on Chapter 2 in *Paying for Agricultural Productivity,* by Alston and Pardey (1999); our discussion of trends in research funding borrows heavily from Pardey et al. (2006) and Chapter 3 in *Paying for Agricultural Produc-*

tivity, by Pardey, Roseboom, and Craig (1999). We refer readers interested in a more complete treatment to these source documents; however, our contribution involves more than simply taking that material and summarizing it. In considering the specific perspective of less-developed countries, we reinterpret and tailor the ideas and arguments, and bring to bear different facts.

Policy Principles

Alston and Pardey (1999) laid out the case for government intervention in agricultural R&D and relevant principles for the determination of the appropriate form and extent of intervention. These arguments are useful for contemplating past and prospective policy changes. The key idea is that incomplete or ineffective property rights over inventions can lead to market failure in agricultural R&D, which means that inventors are unable to fully appropriate the returns to their research investments. Market failures in research can happen at the level of firms within a state or country, states within a country, or among countries—in any context where the distribution of benefits from adopting the results does not closely match the distribution of the costs incurred in doing the research.

Market failure leads to private-sector underinvestment in agricultural R&D, a phenomenon that can account for the consensus in the empirical literature dealing with different commodities and different countries, that agricultural R&D has been, on average, a highly profitable investment from society's point of view (Alston et al. 2000). In turn, this outcome suggests that research may have been underfunded, and that current government intervention may be inadequate.[1]

This is not to say that the amount of government spending necessarily should increase. Changes in government intervention can take many forms. Some commentators propose increasing R&D funding from general government revenues, but this is only one possible alternative. Governments can also change the incentives for others to increase their investments in private or public R&D (as well as influence what research is done, by whom, and how effectively). A premise that government intervention is inadequate implies simply that the nature of the intervention ought to change so as to stimulate either more private investment or more public investment. Policy options available to the government for stimulating private funding or performance of agricultural R&D include

- improving intellectual property protection;
- changing institutional arrangements to facilitate collective action by producers, for instance, by establishing levy arrangements; and

- encouraging individual or collective action through the provision of subsidies (or tax concessions) or grants in conjunction with levies.

Intellectual property rights are applicable or enforceable only for certain types of inventions, and they have the disadvantage that privately optimal prices may exceed socially optimal prices.[2] Commodity-specific levy arrangements are most applicable for commodity-specific R&D of a relatively applied nature (as implemented in Australia, Colombia, and Uruguay, for instance), although more general agricultural R&D could be funded by a more general agricultural levy (as in the Netherlands). In cases where the fruits of invention can be only partially appropriated, a case can be made for partial support from general government revenues through subsidies or matching grants in conjunction with commodity levies, as used in the Australian R&D corporations (see, for example, Alston, Freebairn, and James 2004). To some extent, questions about how to finance agricultural R&D can be separated from who conducts the research, what research is undertaken, and how the R&D process is managed. It is useful to consider these elements as separate issues, but inevitably they become intertwined.

In addition to efficiency gains from increasing the total R&D investment, the government can also intervene with a view to improving the efficiency with which resources are used within the R&D system. Changes over time in economic circumstances imply changes in R&D institutions. Some research activities that were once clearly perceived as the province of the government have become part of the private domain. Examples include much applied work into the development and evaluation of new agricultural chemicals and new plant varieties.

Both in one country over time, and among different countries at the same time, circumstances differ in ways that call for different policies and institutional arrangements. Policies must be suited to the setting. Some restructuring or consolidation of agricultural R&D institutions, in some instances on a geographic basis, is warranted by the changing nature of the research being undertaken; its focus relative to agriculture, agribusiness, and the environment; and the spatial and economic applicability of the results, as well as the changing nature of economies of size, scale, and scope in research. In addition to changes in the organization of research institutions, there is also scope for more economic rationalism in the processes for managing research and allocating research resources and in the structure of incentives for scientists.

Distinctive Features of Less-Developed Countries

These general notions about market failure and options for government action apply generally, but with different specific implications as cases change. Less-developed countries tend to differ from more-developed countries in some systematic ways. In particular, for a number of reasons, the phenomenon of private-sector neglect and national underinvestment in agricultural R&D is likely to be more pronounced in less-developed countries than in developed ones. Why is this so, and what does it imply?

First, less-developed countries are commonly characterized as having a comparatively high incidence of incomplete markets, resulting from high transaction costs and inadequate property rights, which in turn may be attributable to inadequate infrastructure and defective institutions, among other things. To the extent that they exist, information problems, high transport and communications costs, poorly functioning credit markets, and the like, combined with the limited education of some farmers, are likely to make it harder to capitalize on new inventions. In rich countries, we might discount the issues of risk and capital costs as disincentives to investment in invention, but in less-developed countries these factors might take on a greater importance, especially if capital markets do not function well—for whatever reason.

Second, the types of technology often suited to less-developed country agriculture have hitherto been of the sort for which appropriability problems are more pronounced—types that have been comparatively neglected by the private sector even in the richest countries. In particular, until recently, private research has tended to emphasize mechanical and chemical technologies, which are comparatively well protected by patents, trade secrecy, and other intellectual property rights; and the private sector has generally neglected varietal technologies except where the returns are appropriable, as for hybrid seed (see Olmstead and Rhode 2002). In less-developed countries, the emphasis in innovation has often been on self-pollinating crop varieties and disembodied farm management practices, which are the least appropriable of all. The recent innovations in rich-country institutions mean that private firms are now finding it more profitable to invest in plant varieties; the same may be true in some less-developed countries, but not all countries have made comparable institutional changes.[3]

Third, in many less-developed countries, prices have been distorted by policies in ways that diminish incentives and opportunities for farmers to adopt new technologies (see Schultz 1978; Alston and Pardey 1993; and Sunding and Zilberman 2001).[4] Only when we achieve a reasonable rate of inventor appropriability of the returns to the technologies that are applicable in less-developed countries, combined with an economic infrastructure that facilitates adoption of those technologies, can we expect a significant private-sector role to emerge.

Accepting that markets may fail, for whatever reason, we have to consider the possibility that governments in less-developed countries also might fail—in this case, fail to correct the underinvestment in agricultural research—for both economic and political reasons. For instance, and as a fourth factor accounting for their low rates of investment in agricultural R&D, government revenues may be comparatively expensive, or have a comparatively high opportunity cost in less-developed countries. This can be so because it is comparatively expensive to raise government revenues through general taxation measures.[5] And many less-developed countries are characterized by underinvestment in a host of other public goods, such as transportation and communications infrastructure, schools, and hospitals, as well as agricultural science (Runge et al. 2003), which might also have high social rates of return.

Fifth, there are political factors to consider. In rich countries, agriculture is a small share of the economy, and any individual citizen bears a negligible burden from financing a comparatively high rate of public investment in agricultural R&D (for instance, in the United States, the public expenditure of US$3.8 billion on agricultural R&D in 2000 amounted to less than US$14 per person per year). The factors that account for high rates of general support for agriculture in the industrialized countries can also help account for the comparatively high intensity of public agricultural research. In many less-developed countries, where agriculture represents a much greater share of the total economic activity, and where per capita incomes are much lower, a meaningful investment in public agricultural research may have a much more appreciable impact on individual citizens. This burden is felt immediately, whereas the payoff it promises may take a long time to come and will be much less perceptible when it does.

Finally, even many of the rich countries of the world have not had very substantial private or public agricultural science industries. Why should we expect the poorest countries of the world to act like the richest of the rich in this regard?[6] The lion's share of the public (as well as private) investment in agricultural science has been undertaken by a small number of countries; and these have been the countries that have also undertaken the greatest share of scientific research, more generally. Typically, these have been the large economic powerhouses, especially the United States. Differences in per capita income, the total size of the economy, and comparative advantages in science (reflecting not just wealth but also the nature of the society) may all have influenced the international distribution of the burden of agricultural R&D investments.

It might not make economic sense for small, poor, agrarian nations to spend their comparatively scarce intellectual and other capital resources in agricultural science on their own behalf in a world in which other countries can do it so much more effectively.[7] And in the past it has been an effective strategy for many nations to free-ride on the efforts of a few others in agricultural R&D. Both inadvertent technology spillovers and international initiatives such as the CGIAR and bilateral agricultural R&D development aid might have crowded out some national investments in agricultural R&D in less-developed countries.[8]

An important consideration is economies of size, scale, and scope in research, which influence the optimal size and portfolio of a given research institution. In some cases the "optimal" institution may efficiently provide research for a state or region within a nation, but for some kinds of research the efficient scale of institutions may be too great for an individual nation (see, for example, Byerlee and Traxler 2001). Many nations may be too small to achieve an efficient scale in any of the relevant elements of their agricultural R&D interests, except perhaps in certain types of adaptive research. A particular problem for efficiency in agricultural science, especially for many smaller countries, is that there are few effective institutions for financing and organizing research on a multinational basis when the research is applicable across multiple countries, and individual countries are too small to achieve efficient scale (see Chapter 12 in this volume).

Technology Spillovers: Past, Present, and Future

The history of agricultural development shows that agricultural technology need not be home-grown; over the years it has been bought, borrowed, and stolen. For instance, in the late 18th century, Thomas Jefferson, risking the death penalty, smuggled rice seeds out of Italy in the lining of his coat to encourage cultivation of the crop in South Carolina. Agricultural innovations move across borders, both by design and by accident. These technology spillovers imply both international market failures and a case for multinational government action to correct them, paralleling the intranational arguments presented above.

R&D spillovers among geopolitical entities arise when research conducted by one state (or nation) confers benefits on other states (or nations) that are able to adopt the results. Such spillovers have two kinds of implications for research policy. First, they add complications to already awkward policy questions that arise when research is being conducted and funded by state and national governments—such as how much and what mix of research should be undertaken, who should pay for it, who should do it, and what institutional arrangements should be put in place. Second, and perhaps more important, they introduce an additional dimension to incentive problems. The fundamental economic basis for the government support of agricultural research is incomplete appropriability of research benefits by inventors. Research and technology spillovers among research providers within a state can be addressed (at least in principle) by state-government policy, but state-government policy cannot effectively address spillovers across state boundaries.

Similarly, federal-government policy might address spillovers among research providers in different states within a nation, but national-government policy cannot effectively address spillovers among nations.

Alston (2002) reviewed the evidence of agricultural R&D spillovers, with emphasis on the international dimension. The main findings can be stated simply. First, intranational and international spillovers of public agricultural R&D results are very important. In the small proportion of studies that have taken them into account, spillovers were responsible for a sizable share—in many cases, more than half—of total measured agricultural productivity growth and the corresponding research benefits. Second, spillovers can have profound implications for the distribution of research benefits between consumers and producers and thus among countries, depending on their trade status and capacity to adopt the technology. Third, it is not easy to measure these impacts, and the results can be sensitive to the specifics of the approach taken, but studies that ignore interstate and international spillovers are likely to obtain seriously distorted estimates of the returns to agricultural research. Finally, because spillovers are so important, research resources have been misallocated both within and among nations. In particular, international spillovers contribute to a global underinvestment in agricultural R&D that existing public policies have only partly succeeded in correcting.[9] The stakes are large because the benefits from agricultural technology spillovers are worth many times more than the investments that give rise to them.

This volume examines spillovers from a less-developed-country perspective. It is important to note the important role of spillins to the world's poorest countries of technologies from industrialized countries (especially the United States, but also the United Kingdom, France, and others), both individually and through their collective action via the CGIAR. Until recently, much of the successful innovative effort in most of the world's poorer countries applied at the very last stage of the process—selecting and adapting crop varieties and livestock breeds for local conditions using materials developed elsewhere. Only a few larger countries, such as Brazil, China, and India, were able to achieve much by themselves at the more upstream stages of the research and innovation process, even for improved crop technologies for which conventional breeding strategies are widely applied. Until recently that strategy was reasonable, given an abundant and freely accessible supply of suitable materials, at least for the main temperate-zone food crops. Changes in the emphasis of rich-country research, combined with new intellectual property rules and practices and an increased use of modern biotechnology methods, have already begun to spell a drying up of the public pool of new varieties. In addition, and as set out in detail in Chapter 12, the other main source of varietal materials—the CGIAR—has changed its emphasis and is scaling back its role in providing finished material or advanced breeding lines.[10] The reduction in spillovers from these traditional sources means that less-developed countries will have to find new ways of meeting their demands for new varieties.

Research Spending Patterns

The public and private roles in agricultural science have changed, reflecting changing economic conditions in the broader economy as well as in agriculture. Changes have also occurred in institutional arrangements, such as intellectual property rights, and in public attitudes and perceptions. Although many elements of the changes have been common to various countries, reflecting common influences at work, there have been some important divergences among countries as well—especially between the richest and the poorest countries. Pardey et al. (2006) document these changes.

General Trends

Over the last two decades of the 20th century, worldwide public investments in agricultural research increased by 51 percent in inflation-adjusted terms, from an estimated $15.2 billion (in 2000 international dollars) in 1981 to around $23 billion in 2000 (Table 2.1).[11] During the 1990s, for the first time, developing countries as a group undertook more of the world's public agricultural research than the developed countries, but with the Asian and Pacific region and China accounting for more of the developing-country total, and Sub-Saharan Africa losing market share.

What the regional totals fail to reveal is that public spending was concentrated in only a handful of countries. The United States, Japan, France, and Germany accounted for two-thirds of the $10.2 billion of public research done by rich countries in 2000, about the same as two decades before. Similarly, four of the developing countries among those included in this book—China, India, Brazil, and South Africa—spent almost 50 percent of the developing world's public agricultural research money in 2000, up from 37 percent in 1981.

Despite this pattern of strong longer-term growth in spending since the 1970s, for many parts of the world the rapid and quite pervasive growth in spending during the 1970s and early 1980s gave way to a dramatic slowdown during the 1990s. In the rich countries, public investment actually shrank by 0.58 percent annually between 1991 and 2000, compared with an increase of 2.3 percent per year during the 1980s. Spending in Africa grew by only 0.82 percent per year in the 1990s—a much slower rate than during the 1980s (1.25 percent per year). This slowing reflects a longer-run trend: rapid growth in spending in the 1960s gradu-

Table 2.1 Global public agricultural-research spending, 1981–2000

Expenditures (million 2000 international dollars)	1981	1991	2000
Developing countries	6,904	9,459	12,819
Sub-Saharan Africa	1,196	1,365	1,461
China	1,049	1,733	3,150
Asia and Pacific	3,047	4,847	7,523
Latin America and the Caribbean	1,897	2,107	2,454
Middle East and North Africa	764	1,139	1,382
Developed countries	8,293	10,534	10,191
Total	15,197	19,992	23,010
Annual growth rates (percent per year)	**1981–91**	**1991–2000**	**1981–2000**
Developing countries	3.04	2.90	3.14
Sub-Saharan Africa	1.25	0.82	0.99
China	4.76	5.04	4.86
Asia and Pacific	4.33	3.92	4.19
Latin America and the Caribbean	1.13	2.06	2.01
Middle East and North Africa	4.12	1.87	3.35
Developed countries	2.27	–0.58	1.10
Total	2.63	1.20	2.11

Source: Agricultural Science and Technology Indicators (ASTI) data underlying Pardey et al. 2006.

Note: Data are provisional estimates and exclude Eastern Europe and countries of the former Soviet Union.

ally gave way in the 1980s and beyond to debt crises, curbs on government spending, and waning donor support for agriculture in general, and agricultural R&D in particular, during the 1990s. In fact, if large countries like Nigeria and South Africa are excluded, spending for Africa overall actually declined by 2.5 percent per year during the 1990s (Beintema and Stads 2004). Spending in Asia grew by an average of 3.9 percent per year during the 1990s, compared with 4.3 percent annually during the previous decade. Growth slowed in the Middle East and North Africa as well.

China and India are exceptions. Growth in spending during the 1990s averaged 5.04 percent per year in China and 6.37 percent per year in India. Things look a little better in Latin America, too, with spending growing 2.06 percent per year from 1991 to 2000, compared with about half that rate during the previous decade. But the recovery in Latin America seems fragile and is not distributed evenly throughout the region. Public research in countries like Brazil (with public spending approaching a billion dollars a year, a considerably larger commitment than in any of the developed countries besides the United States and Japan) and Colombia did better in the early 1990s but suffered cutbacks in the later part of the decade. Many of the poorer (and smaller) countries have failed to experience any sustained growth in funding for the past several decades.

Research Intensities

Turning now from absolute to relative measures of R&D investments, in 2000, developed countries as a group spent \$2.36 on public agricultural R&D for every \$100 of agricultural output, a sizable increase over the \$1.41 they spent per \$100 of output two decades earlier (Table 2.2). Since 1981, research intensities have risen for the developing countries as a group, but unevenly. Despite having gained a greater absolute share of the developing world's total agricultural research spending, China's agricultural research intensity in 2000 was no greater than in 1981. In other words, China's research spending grew, but its agricultural sector grew just as quickly. Although public research throughout the rest of Asia and Latin America appears to have grown in intensity during the last decade of our data, Africa lost considerable ground, with research intensities now lower than in the 1970s.

Other research-intensity ratios are also revealing. Rich countries spent nearly \$700 per agricultural worker, more than double the corresponding 1981 ratio. Poor countries spent just \$10.21 per agricultural worker in 2000, substantially less than double the 1981 figure. These differences are perhaps not surprising. A much smaller share of the rich-country workforce is employed in agriculture, and the absolute number of agricultural workers declined more rapidly in rich countries than it did in the poor ones. Agricultural research spending per capita rose, too, by an average of only 9 percent for developed countries (from \$10.91 per capita in 1981 to \$11.92 in 2000) and 29 percent in developing countries (from \$2.12 per capita in 1981 to \$2.73 in 2000). Notably, per capita research spending (in terms of both total population and agricultural workers) declined in Africa, the only region of the world where this occurred.[12]

Private and Public Research Roles

By the mid-1990s, roughly one-third of the \$36.9 billion total investment in agricultural research worldwide was by private firms, including those involved in providing farm inputs and processing farm products (Table 2.3). But little of this private research took place in developing countries. The overwhelming majority (\$12.6 billion, or 91 percent of the global total) was conducted in developed countries. In the less-developed countries, where public funds are still the major source of support, the private share of research was just 8.3 percent. (Public funds remain a significant source of support in rich countries, too, accounting for about 45 percent of their total funding in 2000).

Although more than one-half of the world's public R&D dollars are spent in developing countries, only one-third of the public plus private research spending occurs there. In addition, the research-intensity gap between rich and poor countries is wide and growing. As we saw, in 2000, public research intensity was four

Table 2.2 Global public agricultural research-intensity ratios, 1981–2000

Region/country	Expenditures as a percentage of AgGDP			Expenditures per capita (2000 international dollars)			Expenditures per economically active member of agricultural population (2000 international dollars)		
	1981	1991	2000	1981	1991	2000	1981	1991	2000
Developing countries	0.52	0.50	0.53	2.1	2.3	2.7	7.0	8.3	10.2
Sub-Saharan Africa	0.84	0.79	0.72	3.1	2.7	2.3	11.2	10.5	8.2
China	0.41	0.35	0.40	1.0	1.5	2.5	2.5	3.5	6.2
Asia and Pacific	0.36	0.38	0.41	1.3	1.7	2.4	3.8	5.2	7.6
Latin America and Caribbean	0.88	0.96	1.16	5.5	6.6	5.9	45.1	50.5	60.7
Middle East and North Africa	0.61	0.54	0.66	3.2	3.6	3.7	19.2	27.3	30.2
Developed countries	1.41	2.38	2.36	10.9	13.0	11.9	316.5	528.3	691.6
Total	0.79	0.86	0.80	3.8	4.2	4.1	15.1	17.2	18.1

Source: Agricultural Science and Technology Indicators (ASTI) data underlying Pardey et al. 2006.

Note: Data are provisional estimates and exclude Eastern Europe and countries of the former Soviet Union.

Table 2.3 Private and public agricultural R&D investments, circa 2000

	Expenditures (million 2000 international dollars)			Shares (percent)		
Region	**Public**	**Private**	**Total**	**Public**	**Private**	**Total**
Developing countries	12,909	1,108	14,089	91.6	8.4	100
Developed countries	10,191	12,577	22,767	44.8	55.2	100
Total	23,100	13,756	36,856	62.7	37.3	100

Source: Agricultural Science and Technology Indicators (ASTI) data underlying Pardey et al. 2006.

Note: Data are provisional estimates. Combining estimates from various sources resulted in unavoidable discrepancies in the categorization of "private" and "public" research. For example, in Asia data for private spending included nonprofit producer organizations, whereas in Latin America and elsewhere we included research done by nonprofit agencies under public research when possible.

times higher in rich countries than in poor ones; if total private and public spending is considered, the gap grows to more than eightfold, with rich countries spending about $5.27 on agricultural R&D per $100 of agricultural GDP.

Research Knowledge

The eightfold difference in total research intensities is an indication of the present gap in generating new technologies between rich and poor countries. However, a more meaningful measure of a country's technological capacity and a better account of cross-country differences in agricultural productivity is the size of the accumulated stock of knowledge—not merely the amount of investment in current research and innovative activity—it provides. Science is a cumulative endeavor. Innovations beget new ideas and further rounds of innovation, which ultimately add to the cumulative stock of knowledge.

The current stock of knowledge and the contribution of past research spending to that stock is sensitive to the types of science being done, the institutional structures surrounding the science, and the economic context. Some science spending makes persistent and even perpetual contributions to the changing stock of locally produced knowledge; the same spending in societies ravaged by wars, institutional instability, and outright collapse may have a much more ephemeral effect.

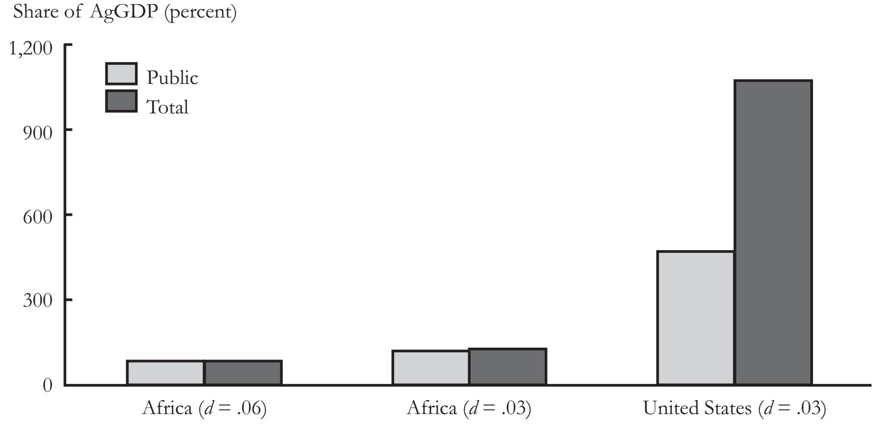
The sequential and cumulative nature of scientific progress and knowledge is starkly illustrated by crop improvement. It typically takes seven to ten years of breeding to develop a uniform, stable, and superior crop variety; but today's breeders build on an accumulation of knowledge. Because breeding lines from earlier research are used to develop new varieties, research of the distant past is still feeding today's research.

Providing adequate funding for research is thus only part of the story. Putting in place the policies and practices to accumulate innovations and increase the stock of knowledge is equally important and almost universally unappreciated. Discoveries and data that are improperly documented or inaccessible (and effectively exist only in the mind of the researcher) are lost from the historical record when researchers retire from science. These "hidden" losses seem particularly prevalent in cash-strapped research agencies in the developing world, where inadequate and often irregular amounts of funding limit the functioning of libraries, data banks, and genebanks, and hasten staff turnover.

Political instability can lead to catastrophic losses, too. Civil strife and wars cause an exodus of scientific staff, or at least a flight from practicing science. Many of Uganda's scientific facilities, for example, were in shreds when its civil war ended in the early 1980s. It is hard to imagine that today's Congo once had perhaps the most sophisticated scientific infrastructure in colonial Africa, comparable to the facilities and quality of staff found in most developed countries at the time.

Figure 2.1 represents financial measures of the stock of scientific knowledge based on research performed in the United States (assuming a baseline rate of depreciation of the knowledge stock of 3 percent per annum) and Africa (for which we show both a 3 percent baseline depreciation rate and a rate of 6 percent per year,

Figure 2.1 African and American stocks of research knowledge, 1995



Source: Pardey and Beintema 2001.

Note: d indicates depreciation rate. The lag time relating innovations, I_t, to present and past research expenditures, R_{t-s}, was taken to be ten years for both regions, so the stock of knowledge for year t, K_t, was formed as $K_t = (1-d)\ K_{t-1} + I_t$, where d is the rate of knowledge depreciation and $I_t = \sum_{j=0}^{10} R_{t-j}$.

which is perhaps more realistic given the instability and lack of infrastructure for R&D throughout much of the region). Knowledge stocks in 1995—representing a discounted accumulation of research spending from 1850 for the United States and 1900 for Africa—were expressed as percentages of 1995 agricultural GDP to normalize for differences in the sizes of the respective agricultural sectors. The accumulated stock of knowledge in the United States was about 11 times the amount of agricultural output produced in 1995. In other words, for every $100 of agricultural output, there existed a $1,100 stock of knowledge to draw upon. In Africa, the stock of knowledge in 1995 was actually less than the value of African agricultural output that year. The ratio of the U.S. knowledge stock relative to U.S. agricultural output in 1995 was nearly 12 times higher than the corresponding amount for Africa. If a depreciation rate of 6 percent instead of 3 percent is used, the gap in American and African ratios is more than 14-fold.

Policy Implications

Agricultural R&D for less-developed countries is at a crossroads. The close of the 20th century witnessed changing policy contexts, fundamental shifts in the scientific basis for agricultural R&D, and shifting funding patterns for agricultural research in rich countries. These changes imply a need to rethink national policies in less-developed countries and reconsider multinational approaches in order to determine what types of activities to conduct through the CGIAR and similar institutions and how to organize and finance them.

Even though there is no evidence to suggest that the world can afford to reduce its rate of investment in agricultural research, and every indication that we should invest more, we cannot presume that the rich countries of the world will play the same roles as in the past. In particular, countries that in the past relied on technological spillovers from the North may no longer have that luxury available to them in the same ways or to the same extent. This change can be seen as involving three elements:

- The types of technologies being developed in the rich countries may no longer be as readily applicable to less-developed countries as they were in the past: the agenda in richer countries is shifting away from areas like yield improvement in major crops to other crop characteristics and even to nonagricultural production concerns like health and nutrition and the environment.

- Applicable technologies developed in richer countries may not be as readily accessible because of intellectual-property protection of privately owned technologies: many biotech companies have little or no interest in developing technologies for less-developed country applications; and even where they have such technologies available, they are often not interested in pursuing potential markets in less developed countries, for a host of reasons.

- Those technologies that are applicable and available are likely to require more substantial local development and adaptation, which call for more sophisticated and more extensive forms of scientific research and development than in the past: for instance, more advanced skills in modern biotechnology or conventional breeding may be required to take advantage of enabling technologies or simply to make use of less-finished lines that must be tailored to local production environments.

In short, different approaches may have to be devised to make it possible for less-developed countries to achieve equivalent access and tap into technological potentials generated by rich countries, and, in many instances, less-developed countries may have to extend their own R&D efforts upstream to more fundamental areas of the science.

Finally, it must be remembered that agricultural R&D is a slow business. As Pardey and Beintema note (2001, p. 2): "It is the accumulation of results over the long haul that accounts for the differences in agricultural productivity observed around the world." In contemplating their evidence on stocks of knowledge, it can be seen that the imbalance between the North and the South is very much greater than the annual flows alone reveal. The tail end of the 20th century saw some evidence of a partial catching up, but the current prospects could spell a dangerous shift toward falling farther behind—and the long-term, dire consequences may not become apparent for some time to come.

Notes

1. One explanation for this government failure is that, just as in the case of private market failure, when the distributions of benefits and costs of government-funded research are not closely aligned, incentives are distorted. If taxpayers in a country bear all of the cost of research that benefits a select group of producers, they have attenuated incentives to fund the amount of research that will maximize net national benefits, particularly if some of the producers who benefit are foreigners.

2. Many research outputs have public-good characteristics to some extent, implying socially optimal prices that may not allow for the recovery of costs. In the case of a "pure public good," one that is nonrival in consumption and non-price-excludable, the socially optimal price is zero (to achieve marginal social benefits equal to marginal social cost and thereby maximize net national benefits). Furthermore, patents and the like confer monopoly privileges, which result in prices above marginal cost, even for rival goods. See Lindner (1993, 2003).

3. Innovations in intellectual property rights regimes and biosafety protocols are seen as critical determinants of appropriability of returns to new crop and livestock technologies, but not all nations have gone as far as the United States in these respects. See Boettiger et al. 2004 for more discussions on these points.

4. The fact that the more-developed countries have distorted prices in the opposite direction is a double-edged sword for the less-developed countries. On the one hand, richer countries are encouraged to produce and innovate more rapidly, further depressing prices faced by less-developed-country producers. On the other hand, as recipients of technology spillovers, the world's poorer producers have also benefited from an enhanced rate of technological development in the North.

5. A dollar of government spending costs society more than a dollar. For every dollar of government revenue, at least a dollar has been taken from someone as taxes (maybe someone living in a different place and time from those where research benefits will be realized). The marginal and average excess burden of taxation rises with increases in the price responsiveness of supply and demand (that is, elasticities) and the size of the tax rate; the total excess burden rises with the square of the tax rate. It follows that a small tax on an agricultural commodity must have a very small total, average, and marginal excess burden (regardless of the elasticities of supply and demand for such a small tax rate) compared with general taxation measures. To this amount, we can add the costs of enforcement, collection, and disbursement of the funds, the costs of compliance, and the social costs associated with market responses to the (dis)incentive effects of taxation (see, for example, Fox 1985; Fullerton 1991; and Alston and Pardey 1996, Chapter 7).

6. As noted by Pardey et al. (2006), investment in the sciences is generally much more concentrated in rich countries (which accounted for about 82 percent of global investment in all the sciences in the mid-1990s, with about 35 percent of that total occurring in the United States alone) than is agricultural R&D (in which rich countries conduct 63 percent of all agricultural R&D and 44 percent of the world's publicly funded agricultural research). Moreover, the geographical concentration of particular classes of agricultural research—for instance, research into agricultural chemicals or machinery—is even greater than that of agricultural R&D in general.

7. As demonstrated by Maredia and Byerlee (2000), it has made economic sense for many less-developed countries to emphasize adapting research results from other countries rather than to participate directly in upstream research activities. Their results indicated that only 41 out of the total of 69 wheat-improvement programs operating in their sample of 39 developing countries could economically justify maintaining fully fledged wheat-breeding programs. For the remaining 28 programs, it would have made sense to restrict the scope of research to screening and selection roles—presuming that varieties from which to select and screen would continue to be available from other national and international sources.

8. Beintema and Stads (2004) found that donor contributions accounted for 35 percent of spending on agricultural R&D for the principle research agencies in a sample of 23 African countries in 2000.

9. There have also been private actions to address these international market-failure problems, including the efforts of philanthropic organizations like the Ford, Rockefeller, and, more recently, McKnight foundations to fund international collaborative research; multinational companies that operate in multiple markets; and private nonprofit entities like CAMBIA in Canberra, Australia, and the Donald Danforth Plant Science Center in St. Louis, Missouri, which conduct research in rich countries that is targeted to the agricultural concerns of poor countries.

10. Norman Borlaug, a winner of the Nobel Peace Prize and previously head of the wheat improvement program at the International Center for Maize and Wheat Improvement (CIMMYT),

pioneered a shuttle-breeding technique wherein two crops of wheat were planted each year (one in northern Mexico, the other in the southern part of the country) to accelerate the turnaround of successive crop generations when breeding improved wheat varieties. A dramatic illustration of the CGIAR's present financial plight is that, for the first time in almost three decades, CIMMYT could afford to plant only one breeding cycle in 2003.

11. All these data involve conversions from local currency units to U.S. dollar equivalents, using purchasing power parities rather than market exchange rates to account for cross-country price differentials. See Pardey, Roseboom, and Craig 1992 for details.

12. Roe and Pardey (1991) provide a political-economy perspective on these various research-intensity ratios.

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Chapter 3

China: An Unfinished Reform Agenda

Shenggen Fan, Keming Qian, and Xiaobo Zhang

Introduction

Agricultural production in China has grown rapidly—relative to other countries—over the past four decades. Much of this growth can be attributed to investments in agricultural research by national and regional governments combined with policy reform and increased use of inputs.[1] After 50 years of development, the Chinese agricultural research system is now arguably the largest in the world, employing over 50,000 senior scientists and spending more than US$3.8 billion in 2002 (measured in 1995 international dollars).[2] However, the system is currently facing a dilemma. Chinese agricultural production is becoming increasingly dependent on new technologies generated by research, especially as agricultural land and other natural resources become more limiting factors. The quantity of agricultural land—and high-quality land in particular—will only decline further in the future with rapid industrialization and urbanization. At the same time, a national policy introduced in the mid-1980s has encouraged research institutes to become financially self-supporting. As a result, on the positive side, research has become more integrated with economic development because research institutes have sought financial support by selling their services. On the negative side, however, areas of research not easily commercialized, including significant aspects of agricultural research, face financial problems as governments at various levels reduce funding for R&D.

The objectives of this chapter are to review the evolution of the organizational structure, institutional management, and financing of the Chinese agricultural research system and to explore reform options to promote future agricultural growth and food security and reduce poverty. We first review the trend in agricultural production and productivity growth in Chinese agriculture, using newly available data and new aggregation methods. We then discuss the institutional and policy environment of the Chinese agricultural R&D system. Next, we analyze major issues in the provision and financing of agricultural R&D in China. This analysis is followed by two case studies: one of a national research institute, and the other of a provincial institute. Finally, we offer some policy choices regarding reform of the existing system in light of emerging challenges in the 21st century.

Production and Productivity in Chinese Agriculture

Over the past several decades, and particularly since 1978, the Chinese economy has performed spectacularly well. Per capita gross domestic product (GDP) grew at 6.2 percent per year from 1952 to 2002. Prior to 1978, the growth rate was only 3.4 percent, but between 1978 and 2002 it jumped to 8.2 percent per year (*China Statistical Yearbook,* various years). The economy has also undergone dramatic and continuing structural change.

In 1952, agriculture accounted for more than half the national GDP, while urban industry and services accounted for 21 and 29 percent, respectively (Table 3.1). The Chinese economy was largely agrarian. By 2002, however, agriculture had declined to around 15 percent of GDP—a rapid decline of about two-thirds of

Table 3.1 China: Structural change in the economy, 1952–2002

Indicators	1952	1960[a]	1970	1980	1990	2000	2002
Share of GDP (percent)							
Agriculture	50.5	*23.4*	38.0	30.1	27.1	15.9	15.4
Industry	20.9	*44.5*	35.6	48.5	41.6	50.9	51.1
Service	28.6	*32.1*	26.5	21.4	31.3	33.2	33.5
Share of employment (percent)							
Agriculture	83.5	*82.1*	80.8	68.7	60.1	50.0	50.0
Industry	7.4	*7.9*	10.2	18.2	21.4	22.5	21.4
Service	9.1	*9.9*	9.0	13.1	18.5	27.5	28.6
Per capita GDP (1995 U.S. dollars)							
Official 1995 exchange rate	46.31	58.3	94.6	144.0	341.7	804.5	924.2
Purchasing power parity[b]	203.6	256.4	415.6	632.9	1,501.9	3,536.1	4,062.1
Exports as percentage of GDP	4.0	4.1	2.5	4.7	16.1	23.1	25.7
Imports as percentage of GDP	5.5	2.9	2.5	5.4	13.9	20.8	23.3

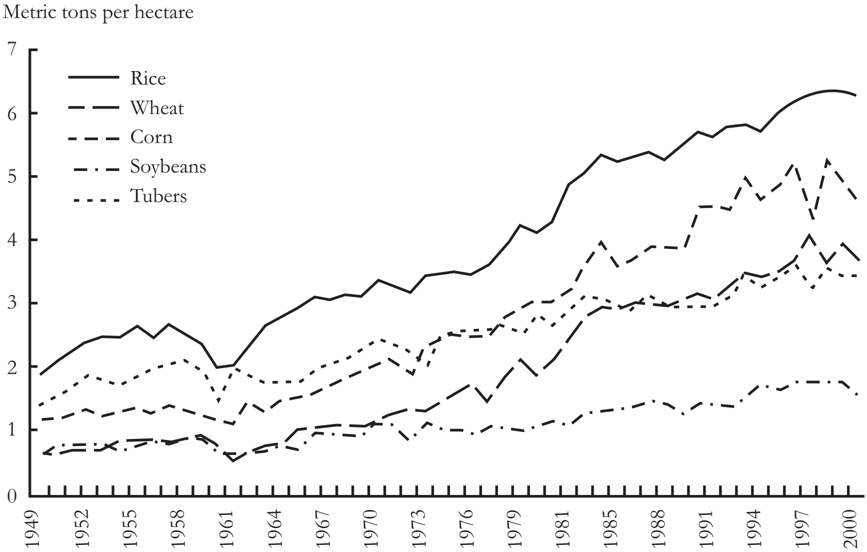
Sources: National Statistical Bureau, various years, for all data, except per capita GDP converted with purchasing power parities (PPPs), which was obtained from World Bank 2004.

Note: Percentages do not always sum to 100 given rounding errors.

[a] Italicized data for 1960 are 1962 values.

[b] Purchasing power parity, or PPP, is an index used to reflect the purchasing power of currencies by comparing prices across a broader range of goods and services than conventional exchange rates.

Figure 3.1. China: Yield of major grain crops, 1949–2000



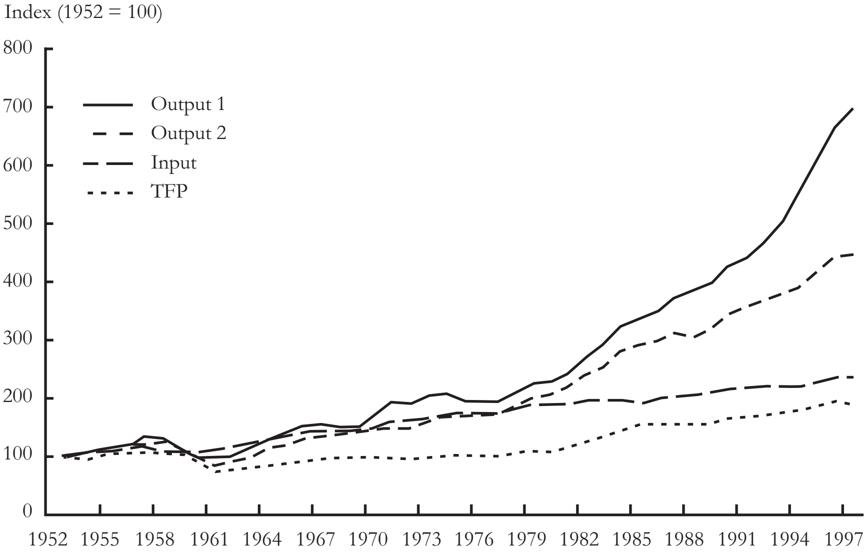
Source: National Statistical Bureau, various years.
Note: Rice is measured as paddy rice.

a percentage point per year. Labor shifts among sectors have been striking. In 1952, more than 80 percent of the national labor force was in agriculture, only 6 percent in urban industry, and 10 percent in the urban service sector. By 2002, less than half the labor force was engaged in agricultural activities; more than 21 percent worked in the industrial sector and 29 percent in the service sector.

Agricultural production has grown at a much faster pace in China than in most other countries for the past 50 years. The yield of rice, the staple of the Chinese diet, has increased from 1.9 tons to 6.3 tons per hectare, a rate of increase of 2.24 percent per year (Figure 3.1). The yield of wheat, another important crop in China, grew even faster, from 0.6 to 3.9 tons per hectare, or 3.4 percent per year. Overall agricultural production grew by 3.3 percent per year from 1952 to 1997 (Figure 3.2). Growth in grain output and production value has been much higher than the population growth over the same period, so that the amount and value of output per capita has increased.[3]

A large proportion of this growth can be attributed to productivity improvement, which in turn comes primarily from new technologies released by the national agricultural research system. Over the period 1952 to 1997, growth in productivity

Figure 3.2 China: Agricultural production and productivity growth, 1952–97



Sources: National Statistical Bureau, various years; Fan and Zhang 2002.

Notes: Output 1 is the official production index reported by the National Statistical Bureau in various issues of China's statistical yearbooks. Fan and Zhang (2002) argue that the National Statistical Bureau may have overreported agricultural production growth in China by using the constant price index in the aggregation, in addition to overreporting the meat and fisheries output. Output 2 is Fan and Zhang's reconstructed production index using the Tornqvist–Theil index and an adjusted meat and fisheries output. Input is the index of total input aggregated using the Tornqvist–Theil approach. TFP is the total factor productivity index, the ratio of total output (output 2) to total input, both constructed using the Tornqvist–Theil index.

accounted for an estimated 47 percent of total production growth in agriculture (Fan and Zhang 2002). Prior to 1979, increased input use accounted for 95 percent of the growth in output, while productivity improvement accounted for only 5 percent. But after 1979, productivity growth accounted for 71 percent of the production growth, while increased input use accounted for less than 30 percent.[4] This trend indicates that future growth in agricultural production will rely on continued productivity improvements.

The Institutional and Policy Environment

One of the distinguishing characteristics of agricultural research in China is the dominance of public research conducted in national and provincial academies, prefectural institutes of agricultural sciences, and agricultural universities. Related county-level activities deal with technology transfer issues, such as demonstration trials, farmer education, and other extension-related work. Private agricultural research is minimal, although private agricultural research and development initiatives have begun to emerge in recent years.

Like many other sectors of the economy, the Chinese agricultural research system underwent substantial reforms in the last decade of the 20th century. The objectives (or at least the stated intentions) of these reforms were to make the system more efficient and more responsive to the needs of the agricultural sector in particular, and to the development of the economy more generally, while reducing the core public funding provided to research institutes in the context of increasing demand for government funds. These reforms resulted in the emergence of nongovernmental funding for agricultural research. In terms of the ownership of R&D institutes and sources of funding, it is useful to distinguish between five types of agricultural research institutions in China: traditional publicly funded and managed research institutes, development firms owned by public agricultural research institutes, government-owned agribusiness firms, shareholder companies, and multinational companies.

Public-Sector Research Institutes

Public-sector research institutes still form the backbone of the Chinese agricultural research system, despite the rapid emergence of other types of research institutions. Public agricultural research at the national level is conducted mainly within academies and institutes under the Ministry of Agriculture, complemented by the research efforts of various institutes under the administrative control of other ministries. Provincial agricultural academies conduct research targeted primarily at local circumstances. At the prefectural level, the emphasis is on applied and adaptive research and development. The principal research entity is the prefectural agricultural research institute, which is generally administered by the prefectural government. Research at this level is important given the relatively large size of prefectures in China.

The Chinese system is highly decentralized in terms of both management and funding (Table 3.2). Based on 2002 data, only about 12 percent of the scientists and engineers (excluding university personnel) are employed by national institutes. A large proportion of researchers (49 percent) work in institutes administered and often largely financed at the provincial level, while the remaining 39 percent work in prefectural institutes. There is a marked disparity in the average size of the institutes: the national institutes employ an average of 70 scientists per institute, the provincial institutes half this number, and prefectural institutes just 19 scientists

Table 3.2 China: Vertical structure of agricultural research institutes, 1989 and 2002

Category	National	Provincial	Prefectural	Total	National	Provincial	Prefectural	Total
Number of institutes	56	423	620	1,099	59	429	608	1,096
Number of staff (total)	13,590	65,124	46,562	125,276	11,641	45,086	35,622	92,349
Number of scientists and engineers	5,676	17,827	10,161	33,664	4,114	16,458	11,355	31,927
Scientists and engineers per institute	101.36	42.14	16.39	30.63	69.73	38.36	18.68	29.13
Research expenditures (million yuan, 1999 prices)	270	985	654	1,909	1,378	2,923	1,408	5,759
Research expenditure per staff member (yuan, 1999 prices)	19,868	15,125	14,046	15,238	118,375	64,832	39,526	62,361
Research expenditure per scientist or engineer (yuan, 1999 prices)	47,569	55,253	64,364	56,707	334,954	177,604	123,998	180,380

Source: Ministry of Agriculture, various years.

Note: Data pertain to the nonuniversity institutes within the Ministry of Agriculture system only.

per institute. The average spending per staff member at the national level for 2002 was about 120,000 yuan, roughly double the provincial level and triple the prefectural level. These data are generally consistent with the notion of larger, more scientist-intensive institutes at the national level that focus on pre-technology rather than site-specific research. Provincial and prefectural institutes are generally smaller, less scientist-intensive, and involved in more localized, adaptive research and technology development activities.

A distinctive aspect of the agricultural research system in China is that research is institutionally separated from education and extension. The Chinese Academy of Agricultural Sciences (CAAS) falls under the administrative jurisdiction of the Ministry of Agriculture; provincial academies are under the jurisdiction of parallel departments in provincial governments. Prior to 2000, there were seven key national agricultural universities (China [formerly Beijing], Nanjing, Shenyang, Northwest, Central, South, and Southwest), also under the jurisdiction of the Ministry of Agriculture. Provincial agricultural universities were managed by their respective provincial governments. But in 2000, the management of all agricultural universities was transferred to the education system. At the national level, three key agricultural universities—China, Nanjing, and Central—are under the jurisdiction of the Ministry of Education, while provincial agricultural universities or colleges come under the supervision of the provincial department of education. Extension is the responsibility of the Department of Agriculture, with very little involvement by provincial agricultural universities or academies of agricultural sciences. This system contrasts sharply with the U.S. land-grant system, which integrates educational, research, and extension activities. The separation between research, education, and extension has inhibited the integration of technology generation and transfer activities into Chinese agriculture.

Development Firms Owned by Public Agricultural Research Institutes

Increasing demand for agricultural research funding strained government budgets in the mid-1980s. Moreover, the government was dissatisfied with the performance of the agricultural research agencies. Overstaffing, compartmentalization, lack of coordination, and duplication of research efforts left the impression that agricultural research was an expensive and not very effective form of government investment. In particular, the government was concerned about the weak linkage between research and the needs of producers and the low rate of technology adoption.

In March 1985, the Communist Party's Central Committee called for an overhaul of the Chinese R&D system. Many reforms were proposed in the official government document titled "Decision on the Reform of the Science and Technology Management System," and a similar decision was promulgated by the State Council in 1987. Since then there have been about 40 government decisions, regulations, and laws involving reforms of the science and technology system. The main initiatives spelled out in the 1985 and 1987 government documents included changing the basis by which research institutes were funded, encouraging the commercialization of technology and the development of technology markets, and rewarding individual scientists based on their performance. The overriding purpose of the reforms was to make the science sector more responsive to rapidly changing market and economic realities. The principal reform was to modify the funding mechanism in ways that encouraged research institutes to establish contacts with technology users and to conduct research and development that would directly support agricultural enterprises. The direct allocation of funds, consisting almost entirely of block grants to research institutes, was replaced by a mixed system of block grants supplemented with mechanisms whereby institutes competed for project funding from the government and international donors, while also marketing various services directly to farmers and others.

After the 1985 reforms, many research institutes began establishing commercial enterprises or firms. However, the impact of these commercial endeavors on Chinese agricultural innovation has been mixed. At first, these firms were not independent legal entities. Moreover, their businesses were not necessarily related to their research but were developed opportunistically, involving any business or commercial activity that seemed likely to generate revenues. For example, the Institute of Taihu and the Institute of Lixiahe in Jiangsu province, both well known in China for their excellent research programs, produced mineral water and manufactured spare parts for automobiles, respectively. Many institutes at the Chinese Academy of Agricultural Sciences own restaurants, grocery stores, and commercial office complexes, but a lack of capital and management skills resulted in low profits and exposed many research institutes to significant business risks, which they are generally ill equipped to handle. An example was the China National Rice Research Institute in Hangzhou, which began manufacturing monosodium glutamate in 1988. It eventually lost more than 10 million yuan and was saddled with many legal and financial problems. The factory recently went bankrupt.

Another limitation was that many researchers were inexperienced in extension or in dealing with farmers about commercial issues. Those who are active and successful in their research resent the diversion because it detracts from their research time, whereas those prepared to become involved in the transfer of research technology often receive little or no financial reward for their efforts. This separation between research and extension remains unresolved, although the commercial activities and spin-offs of many public research institutes have, in part, substituted for the lack of formal links between extension and research.

Finally, many farmers were either unable or unprepared to pay for technology. In some cases, where high-quality seed or propagation material of perennial crops such as fruit trees was offered, payment was less of a problem, but where the advice or technology was related to an activity regarded as public-good research, farmers expected it to be provided free of charge.

Since the mid-1990s, based on the experience of the previous five to ten years, many public agricultural research institutes have focused their business activities on research-related industries (such as seed, chemicals, vaccines, and so on) to strengthen their competitiveness. They have also begun to set up legally independent companies to avoid direct exposure to risk. The operations of the parent institutes and their associated commercial businesses have become more clearly separated. For example, the seed company of the Institute of Vegetables and Flowers (IVF) at the Chinese Academy of Agricultural Science (CAAS) was established in 1990. Scientists at IVF are responsible for developing and field-testing new varieties. As promising new parent lines for hybrid vegetable seeds are developed, they are made available to the seed company of IVF, which then conducts demonstrations in targeted markets, produces hybrid seeds, and finally markets them. Since 1990, the seed company has earned more than 10 million yuan annually, and about 90 percent of the revenue has been returned to the IVF. The IVF allocates 10 percent of this income to the breeders as a bonus, and the balance is used to cover general research and operational costs.

These commercial enterprises have not only been instrumental in transferring and commercializing technology developed by their parent institutes, as was expected and encouraged by the government, but have also generated substantial revenues to help underwrite the operations of their parent institutes. In 2000, 73 companies at CAAS generated 120.5 million yuan in profit, complementing 243.4 million yuan in core funding from the central government.

Agribusiness Firms Owned by Governments

Revenue-generating businesses include state-owned seed, agricultural, food, chemical, and machinery enterprises. In the former planned economy, these companies received technologies free of charge from the public agricultural research institutes. Since the 1985 reforms, many public research institutes have opted to commercialize their own research and generate income to subsidize their costs, leading to significant awareness of the intellectual property rights (IPR) aspects of agricultural R&D (Koo et al. 2003). Consequently it has become increasingly difficult for agribusinesses to freely access technologies from the public research institutes. In response, some large state-owned companies have negotiated research contracts with public research institutes to license the use of their technologies (involving various up-front, lump-sum payments or per-unit fees based on subsequent sales), while others have opted to develop their own in-house R&D capacities.

An absence of data means that the total R&D investment made by state-owned agribusiness is unknown. A case study of the Chinese seed industry (Qian 1999) indicated that no improved varieties were developed by companies prior to 1985. In contrast, in 1999, 86 improved varieties were released by state-owned and private companies, although these accounted for less than 2 percent of the total varieties released.

Shareholder Companies

Shareholder companies aligned with agricultural technologies have emerged rapidly in recent years. Most of these companies grew out of the development firms founded by public research institutes or agribusiness firms owned by governments. As they grew, many were listed on the stock market to mobilize operating capital. For example, the former Technology Development Company, a very successful development firm owned by the Hunan Academy of Agricultural Sciences, became a listed company in 2000 and mobilized about 700 million yuan from shareholders. The former national livestock company and the fisheries company (both previously owned by the Ministry of Agriculture) also became listed companies in 2000, with a majority holding retained by the government. These three companies each invested several million yuan in agricultural R&D in 2000.

The central government designated 151 of the country's largest agricultural companies as leading companies in agriculture in 2000, most of which were shareholder companies. The government gave these companies preferential policy treatment, including tax exemptions and low-interest loans, conditional on their investing a certain portion of their revenue in agricultural R&D.

Multinational Companies

According to Rozelle, Pray, and Huang (1999), technology flows through multinational firms have led to rapid gains in productivity and output in China's agricultural sector.[5] These firms may play a larger role in the future, given China's recent entry into the World Trade Organization (WTO). For example, modern technology has been introduced in the poultry industry by importing parental genetic stock and breeding materials and by the introduction of superior animal feed milling and mixing methods, coupled with the development of improved poultry genetics.

But the insecure nature of property rights in China means that much potential remains to be realized from the involvement of multinational companies. Various laws and regulations are in place to protect property rights, but their enforcement is weak (Koo et al. 2003). So far, most of the plant breeding and screening research by foreign firms has been on hybridized vegetables and sunflower seeds, because these varieties are hard to duplicate as long as the hybrid parents are kept confidential. In addition, these seeds are not monopolized by the state-owned seed companies; in contrast, the sale of seeds for principal food crops (especially hybrid rice and maize, in which seed quality is difficult to assure) has been strictly limited to the state-owned seed companies, although these restrictions have been relaxed recently. Large private seed companies are now able to market seed varieties that they have developed or acquired.

The weak enforcement of intellectual property rights is a major concern for corporations with duplicable technologies. Profitable markets have developed for some pesticide firms whose products contain active ingredients that are complex and difficult to duplicate, while other pesticides are readily copied (some illegally) and sold at low prices. Transnational corporations that can prevent technology loss by technical means do so; but agrochemicals are widely reported to be reverse engineered. Even when technology can be protected and market demand is high, fragmented retailing and wholesaling networks limit market penetration (Rozelle, Pray, and Huang 1999).

Provision and Financing of Agricultural R&D

Spending on Agricultural Research

Research expenditures. The amount of investment in agricultural research was quite modest during the first five-year plan (1953–57), averaging 130 million 1999 yuan, although the national government actively promoted the establishment of a number of agricultural research institutes (Table 3.3). This was followed by the Great Leap Forward, a program by which the government sought to jump-start the development process through the mass mobilization of people and financial resources in large public-works endeavors. As a consequence of these policies, the investment by the central government throughout the Chinese economy ballooned to unrealistic and unsustainable levels, with expenditures on agricultural research more than doubling in just three years, beginning in 1958. The ensuing policy readjustments, instigated in 1961, reduced 1962 agricultural research expenditures to less than 50 percent of those prevailing just two years earlier.

From this lower level, public investment in agricultural research in China steadily increased until the Cultural Revolution, which began in 1966. Research expenditures again contracted sharply, and the earlier growth in research personnel ceased. Not until 1972 did the system return to a more stable and balanced pattern

Table 3.3 China: Public investment in agricultural research, 1953–2002

Period	Agricultural research expenditures (million constant 1999 yuan per year)	Number of scientists	Expenditures per scientist (constant 1999 yuan per scientist year)	Share of total government spending (%)	Share of total R&D expenditures (%)	Share of total government spending in agriculture (%)	As a percentage of total AgGDP (%)
1953–57	130	NA	NA	NA	NA	1.49	0.07
1958–60	896	140,789	6,366	0.38	10.17	3.25	0.55
1961–65	766	102,498	7,469	0.56	10.24	3.90	0.41
1966–76	1,158	99,657	11,621	0.45	9.93	4.53	0.36
1977–85	2,429	80,278	30,257	0.56	10.34	5.24	0.44
1986–90	3,085	57,564	53,598	0.51	11.90	6.16	0.38
1991–94	3,808	61,545	61,876	0.54	14.29	6.14	0.39
1995–2000	4,590	83,424	55,016	0.53	12.06	8.42	0.34
2002	7,837	53,461	146,491	0.36	9.75	5.46	0.49

Sources: Fan and Pardey 1992, 1997; National Statistical Bureau, various years; and State Science and Technology Commission, various years. See Appendix Table 3A.1 for annual data.

Note: NA indicates data are not available.

of growth. Particularly since 1979, the central government has made a fairly sustained effort to strengthen the nation's agricultural research capacity, with real expenditures growing at 4.8 percent per year over the ensuing decade. However, expenditures failed to grow further during the first half of the 1990s and did not begin to grow again until 1998. This recent surge in spending reflected a refocused attention on food security concerns and a new thrust directed more generally to high-end technology, including biotechnologies relevant to agriculture. For example, the investment in agricultural biotechnology research increased from 16 million yuan in 1986 to 92 million yuan in 1999 (in 1999 prices), with an annual growth rate of 14 percent per year (Huang et al. 2001). This growth rate was three to four times higher than the growth in overall agricultural research expenditures during the same period.

Share in total government expenditures. Agricultural research expenditure as a percentage of total government expenditure was relatively low in the 1950s, ranging from 0.11 percent during 1953–57 to 0.38 percent during 1958–60. Since then it has been quite constant, peaking at 0.56 percent during 1977–85. Expenditure on agricultural research as a percentage of total national R&D expenditure was also quite constant, except during 1966–76 and in 2002, when it was at its smallest for the past several decades. Overall, China's share of total R&D spending directed toward agriculture has fluctuated between 10 to 14 percent. In contrast, research expenditure as a percentage of government spending on agriculture has generally increased over time, from about 1.49 percent during the years 1953 to 1957 to 8.42 percent for the years 1995 to 2000. This indicates that, within the agricultural sector, the government has placed increasing emphasis on research and development. The recent decline in agricultural R&D as a share of government spending on agriculture reflects a more rapid increase in government spending on agriculture relative to the growth in government spending on agricultural R&D.

Research intensity. Agricultural research intensity (ARI) ratios, expressing expenditure on public sector agricultural research as a proportion of the value of agricultural product, are commonly used indicators of the support to national agricultural research systems (NARSs). China's agricultural research-intensity ratio (0.55 percent) was above the less-developed country (weighted) average of 0.47 percent in the early 1960s (Pardey, Roseboom, and Anderson 1991). Even during the Cultural Revolution, China maintained a respectable official level of investment in agricultural research. Since then, the ratio has decreased, reflecting an extraordinarily rapid growth in agricultural output and a generally slower growth in agricultural

R&D spending. By the late 1990s, the latest period for which comparative data are available, China's ARI (0.34 percent in 1995–2000) was about half the developing country average (0.62 percent in 1995) and roughly one-eighth of the developed-country average for public research (2.64 percent in 1995). In 2002, China's ARI jumped to 0.49 percent, reflecting a 35 percent increase in agricultural research expenditures since 2000, as against a 5.7 percent increase in agricultural GDP. This rapid increase in agricultural research investment reflects the government's intention of using science and technology as a means of increasing food security and improving agricultural productivity and efficiency under an increasingly open and internationally competitive agricultural trade regime.

Funding Mechanism and Sources of Agricultural Research

Funding Mechanisms

The State Planning Commission finalizes the annual budgets for all ministerial spending at the national level. It also authorizes the disbursement of central government funds to the various ministries, as well as to the State Science and Technology Commission (SSTC). The SSTC is in turn responsible for allocating the science and technology funds at its disposal to the various agricultural and non-agricultural ministries and national research agencies such as the Chinese Academy of Science (CAS) and, to a limited extent, the Chinese Academy of Agricultural Science (CAAS). At these upper levels of government, allocation procedures are largely driven by precedent and political considerations. Within the respective ministries and agricultural research agencies (such as CAAS), there are currently no formally established or transparent mechanisms for setting research priorities and allocating funds. Project funds that support labor and operational costs have been increasingly allocated through competitive funding mechanisms. For example, funds from the National Natural Sciences Foundation, National Social Sciences Foundation, National Young Scientists Foundation, and other government funding agencies are allocated based on peer reviews.

Funding mechanisms at the provincial and prefectural levels parallel those at the national (or, in Chinese parlance, state) level. Some national funds flow to local government agencies, in some instances from the national to the provincial institutes in support of collaborative research activities. But because government financing within China is highly decentralized, the funds available to provincial and prefectural planning commissions are principally generated through locally administered public financing instruments (for example, taxes on industry and commerce, agricultural land taxes, and resource extraction taxes).

Funding for most research institutes consists of both core and project funds. Core funds, which are mainly used for salaries, are allocated to various organizations by central and local finance departments at the various levels of government, on the recommendations of their counterpart Science and Technology Commissions.

Funding Sources

Prior to the mid-1980s, government funds were the dominant source of support for agricultural research, and even in 1987 they still accounted for more than 70 percent of the total agricultural research expenditures (Table 3.4). Since the reforms of the mid-1980s, research institutes have been encouraged to generate income by providing services to other units or by fulfilling assigned research tasks. Part of these earnings may be retained for use as science and technology research funds by the research units that generate them. As a result, the government's share of total funding has declined dramatically, and development income (meaning income earned from commercial activities) has become almost as important as core government funding. In 1999, only about half the total funding for the system was from the government. Almost 45 percent was income generated by research institutes from services and commercial activities that increasingly draw on the

Table 3.4 China: Income source shares for agricultural research institutes

Year/level	Government	Development[a]	Loans	Other	Total
1987					
National	86.2	12.8	0.2	0.8	100
Other	66.7	26.5	4.2	2.6	100
Total	70.5	23.9	3.4	2.2	100
1993					
National	68.1	26.2	3.4	2.3	100
Provincial	45.2	44.1	7.3	3.4	100
Prefectural	42.8	39.2	13.8	4.2	100
Total	47.1	40.2	9.1	3.6	100
1999					
National	52.2	45.7	2.1	0.0	100
Provincial	51.0	43.3	5.7	0.0	100
Prefectural	43.4	46.8	9.8	0.0	100
Total	48.5	44.9	6.6	0.0	100
2002					
National	64.0	31.4	0.6	4.0	100
Provincial	59.5	28.9	2.9	8.7	100
Prefectural	59.5	27.0	8.1	5.4	100
Total	60.7	29.0	3.7	6.6	100

Source: Ministry of Agriculture, various years.

Note: The data for the national level cover Ministry of Agriculture institutes only; forestry and universities are excluded.

[a] Represents self-generated funds, largely from the sale of goods and services.

technologies arising from R&D. It is likely that an even greater share of the funds available for agricultural R&D will come from such sources, given the incentives to underreport such funding: for example, an institute associated with a national academy such as CAAS must pay a proportion of its self-generated income (perhaps up to 30 percent) to the academy. Development income is often used by research institutes to subsidize researchers' salaries and other benefits, although it is rarely used directly for research.

In recent years the government has ratcheted up its support to science and technology, partly because of improvements in the overall budget situation and partly because it has placed a higher priority on science-based growth strategies. And, perhaps more important, policymakers have begun to realize the public-good dimensions of agricultural research. Consequently, in 2002, government funding jumped to more than 60 percent of the total income received by agricultural research institutes, while the share of development income declined to 29 percent.

Allocation of Research Funds among Subsectors

China has given top priority to crop research, particularly in grain crops, for the past several decades. In 2002, China spent 51 percent of total agricultural research resources on crop research, declining from a peak of 65 percent in 1989 (Table 3.5). This trend is consistent with the changing contribution of crops to total production value (54 percent in 2002). Livestock research accounts for only about 10 percent of total research resources, but the sector accounts for almost 30 percent of the total production value. The fisheries sector accounts for about 7 percent of total research resources but more than 10 percent of the total production value. On the other hand, the forestry sector accounts for only 3.7 percent of total production value but double that in terms of its share of research resources. Based on congruence between the share of research expenditures and the value of the respective sector, there appears to be a substantial overinvestment in forestry research and underinvestment in the livestock and fisheries sectors. Although a more careful study is needed to make definitive conclusions, it appears that China needs to invest more in livestock and fishery research. This shift will be particularly important in the future, as these two subsectors will be the major sources of growth in agricultural production.

Institutional Case Studies

The Chinese Academy of Agricultural Sciences

Founded in 1957, CAAS is the national academy engaged in agricultural R&D, excluding forestry and fisheries. It constitutes the largest and arguably most impor-

Table 3.5 China: Shares of research expenditures among subsectors, 1987–99, 2002

Year	Crop	Forestry	Animal husbandry	Fisheries	Water conservancy	Other	Total
1987	52	13	9	9	10	7	100
1988	54	10	13	9	9	5	100
1989	65	9	8	6	6	6	100
1990	55	11	10	7	9	8	100
1991	52	10	15	8	9	6	100
1992	51	10	16	7	10	6	100
1993	50	9	15	7	11	8	100
1994	50	8	16	7	11	8	100
1995	53	8	15	7	10	7	100
1996	56	9	13	7	11	4	100
1997	58	10	8	7	12	5	100
1998	58	10	9	8	11	4	100
1999	58	9	10	7	10	6	100
2002	51	10	8	6	10	15	100

Sources: Ministry of Agriculture, various years.

Note: National-level data cover Ministry of Agriculture institutes only; forestry and universities are excluded.

tant agricultural R&D institution in China. To a large extent, the structure and performance of CAAS reflect the government's policies on research in general and are therefore indicative of the future of Chinese agricultural research.

This section reviews key aspects of the reforms of CAAS by analyzing the changes in organizational structure, human resource management, funding sources, research priorities, and development and commercial activities.

Organizational structure. CAAS is administratively affiliated with the Ministry of Agriculture (MOA) but is largely influenced by the R&D policy of the Ministry of Sciences and Technology (MOST). In terms of bureaucratic hierarchy, the president of CAAS is ostensibly equivalent to the vice minister of the MOA, but CAAS has no direct administrative control over the provincial academies of agricultural sciences. CAAS is an independent legal entity, consisting of 8 departments at its headquarters, 1 graduate school, 1 publishing house, and 39 institutes (15 located in Beijing and 24 in various provinces across China).

All the institutes under CAAS are independent legal entities, operating autonomously in terms of fund-raising, staff recruitment, and daily operations, but the director general and deputy director general of each institute are appointed by CAAS headquarters. A typical institute has 1 director general, 2 to 4 deputies, 4 management offices—administration, human resources, research management, and development—and 8 to 15 research divisions.

Table 3.6 China: Composition of CAAS personnel, 1994–2001

Year	Research staff	R&D management staff	Business staff	Support staff	Retirees	Total
1994	3,340	1,136	927	1,598	2,878	9,879
1995	3,239	1,073	1,563	NA	3,119	8,994
1996	3,351	982	1,187	1,339	3,442	10,301
1997	3,602	1,089	1,283	1,193	3,978	11,145
1998	3,265	904	1,086	1,137	4,010	10,402
1999	3,018	961	1,436	1,208	4,597	11,220
2000	3,133	982	1,534	945	4,581	11,175
2001	3,003	949	1,428	1,037	4,962	11,379

Source: Chinese Academy of Agricultural Sciences, various years.

Note: NA indicates data are not available.

Human resources. Table 3.6 presents the personnel structure of CAAS during the period 1994 to 2001. The total number of personnel increased slightly, with reductions occurring in the number of research, management, and support staff. Notably, the business staff increased markedly, and the number of retirees soared from 2,878 to 4,962 in the period observed. Over time, as in most Chinese public institutes, these retirees have taken a larger share of the CAAS payroll and become a significant budgetary burden.[6]

Although the total number of staff fell, the number with higher degrees rose. Staff holding Ph.D.s increased from 136 in 1994 to 371 in 2001 (Table 3.7). The number holding bachelor's and master's degrees also grew in proportion to the total number of R&D staff.

Table 3.7 China: Education levels of CAAS personnel, 1994–2001

Year	R&D staff	Ph.D. degrees	M.Sc. degrees	Bachelor's degrees	College
1994	6,074	136	732	922	2,808
1995	5,873	149	728	920	2,774
1996	5,650	204	711	911	2,482
1997	5,884	220	754	978	2,613
1998	5,306	245	688	924	2,269
1999	5,187	292	669	961	2,193
2000	5,060	338	704	1,007	2,090
2001	4,989	371	683	1,006	2,072

Source: Chinese Academy of Agricultural Sciences, various years.

Table 3.8 China: Allocation of CAAS research expenditure, 1994–2001

Year	Basic research	Applied research	Experimentation and development	Other	Total
Constant 1994 yuan (thousands)					
1994	7,390	17,463	6,533	4,694	36,080
1996	5,918	24,334	10,670	6,937	47,859
1997	6,336	32,554	13,480	11,057	63,427
1999	11,371	44,003	14,423	17,825	87,622
2000	16,806	49,840	34,571	23,160	124,377
2001	26,062	59,598	40,820	32,165	158,645
Percentage					
1994	20	48	18	13	100
1996	12	51	22	14	100
1997	10	51	21	17	100
1999	13	50	16	20	100
2000	14	40	28	19	100
2001	16	38	26	20	100

Source: Chinese Academy of Agricultural Sciences, various years.

Note: Data for 1995 and 1998 were not available. Percentages do not always sum to 100 given rounding errors.

Research priorities. CAAS's mandate is to undertake basic, so-called basic applied, and applied research and development of strategic importance to China. In reality, however, most of the research is quite applied. Table 3.8 shows CAAS's research orientation as reflected by its expenditures between 1994 and 2000. Even in real terms, CAAS expenditures have grown remarkably. Evaluated in 1994 constant prices, total spending increased from 36.08 million yuan in 1994 to 158.65 million yuan in 2000. Although the proportions of CAAS spending directed to other types of research expenditure have increased, applied and developmental research (Table 3.8, data columns 2 and 3) still dominate, accounting for almost two-thirds of the CAAS total.

Development activities. Managerial and support staff numbers were cut by 27 percent between 1994 and 2001 as a direct consequence of reforms. Most of these staff were transferred to development or commercial activities, and the income generated from these activities accounted for a larger share of the total income. The number of staff engaged in development and commercial activities rose from 927 to 1,428 over the same period, accounting for 9 percent of total staff. The income from development and commercial activities increased by 56.5 percent to a total of 23.94 million yuan in 2001 (1994 prices).

Most of the commercial undertakings took the form of spin-off companies rather than revenue-raising efforts through technology licensing or royalty arrangements.

Table 3.9 China: CAAS funding sources, 1994–2001

	Government sources		Nongovernment sources	
Year	Constant 1994 yuan (millions)	Share (%)	Constant 1994 yuan (millions)	Share (%)
1994	192.37	71.21	51.26	18.97
1995	207.10	70.51	63.92	21.76
1996	235.38	69.17	80.50	23.14
1997	270.49	66.83	113.53	28.05
1998	182.58	54.57	130.77	39.09
1999	263.68	51.64	237.29	46.47
2000	270.70	51.04	251.77	47.47
2001	400.76	55.73	313.16	43.55

Source: Chinese Academy of Agricultural Sciences, various years.

Note: Shares do not sum to 100 percent because a third category, bans, is not shown.

As of 2001, there were 72 companies operating within CAAS, with each of the academy's institutes operating about two enterprises. As previously mentioned, these companies are closely linked with their parent institutes, making use of institute staff to commercialize and market the research products of the respective institutes. A share of the profits reverts to the parent institute to subsidize salaries and operational costs. In 2001, the 72 companies generated about 42 percent of CAAS's total revenue. The companies not only generate revenues to supplement public funding but also promote the application of research more relevant to on- and off-farm production needs.

Funding sources. Between 1994 and 2001, public funding for CAAS more than doubled, from 192.37 million to 400.76 million yuan (Table 3.9). Nongovernment funding increased fivefold, from 51.26 million yuan to 313.16 million yuan, most of which was generated through commercial activities. The proportion of government funding decreased from 71.2 percent to 55.7 percent, while nongovernment funding increased from 19 percent to 43.6 percent. As the advancing reforms intended, CAAS could no longer rely on public funding alone, and it seems the reforms have effectively diversified the academy's funding channels.

Research output. A key question is whether the diversification in funding sources and implementation of new incentive systems have adversely affected research productivity. China has yet to develop an evaluation system to assess the performance of the research institutes. Table 3.10 provides some indications of the general status of CAAS's research output. The volume of published science and technology papers

Table 3.10 China: CAAS research output, 1994–2001

	Published research papers			Patents	
Year	Total	Published abroad	Published books	Applications	Authorizations
1994	2,327	206	89	NA	NA
1995	2,835	258	110	NA	NA
1996	2,784	217	131	16	5
1997	2,742	181	123	15	12
1998	2,562	185	104	39	18
1999	2,842	198	211	26	21
2000	2,668	206	145	32	18
2001	2,396	174	167	39	26
1994–2001	21,156	1,625	1,080	167	100

Source: Chinese Academy of Agricultural Sciences, various years.

Note: NA indicates data are not available.

increased only slightly between 1994 and 2000. By 2001, the number of published scientific papers totaled 21,156, including 1,625 published abroad. In contrast, the number of published books has increased dramatically, but in China books are generally not refereed or peer-reviewed and hence are much easier to publish than refereed papers. In the current performance-evaluation system, books are ranked at least as high as refereed articles.

The number of patent applications in China grew steadily between 1994 and 2001. Since 1996, CAAS has submitted more than 167 patent applications to the National Patent Agency, indicating, perhaps, that CAAS researchers are coming to appreciate the implications of protecting intellectual property when commercializing innovations. Each year during this period the CAAS's research projects won about 10 national prizes, 20 regional or local prizes, and more than 50 provincial and ministry prizes.

In summary, in the eight years up to 2001, tracking the number of publications or patent approvals produced no clear indication that research productivity at CAAS has been materially affected by the changed circumstances.

The Jiangsu Provincial Academy of Agricultural Science

Jiangsu is one of the most advanced provinces in China in terms of agricultural production and research. The Jiangsu Academy of Agricultural Science (JAAS) is the largest of the provincial agricultural academies, with more than 2,000 full-time employees in 1998 (Qian, Zhu, and Fan 1997). Because Jiangsu has been a pioneer of efforts to reform China's agricultural research and development system, it is an interesting institution to study in terms of the R&D changes taking place.[7]

Institutional aspects. JAAS is a comprehensive public agricultural research institution directly administrated by the Jiangsu Provincial Government. Founded in 1932, it was originally named the National Agricultural Research Institute (NARI) because Nanjing was the national capital at the time. The early organizational structure largely mimicked the Soviet system of the 1950s, but China's transition from a planned to a market economy brought about a demand for institutional change in the agricultural R&D sector. Beginning especially in the early 1980s, the provincial agricultural R&D system in Jiangsu underwent a series of substantial reforms.

In 1982, the provincial government introduced guidelines for reform titled "Opinion on Strengthening Agricultural R&D" (see Wang 2000). The guidelines called for research institutes located at headquarters to focus on projects broadly relevant to the ecology of the province, leaving the regional institutes to focus on more localized, adaptive research. Since then, funds have been reallocated to reflect this intent.

Based on further guidelines in 1985 from the central government for reform of the science and technology sector, the Jiangsu Provincial Government enacted a decree in 1988 to change the system of performance appraisal and promotion. Under the old system, promotions were largely determined by duration of service, whereas now—with a view to providing incentives and enhancing productivity—they are based on performance. Institutions like JAAS proposed detailed guidelines for performance evaluations. For example, single-authored journal articles carry greater weight for evaluation purposes than coauthored articles. Performance evaluation and ranking have profound implications for employees in China: they can affect all aspects of a researcher's life. Public research institutions continue to carry the responsibility for providing employees and retirees with benefits, including housing subsidies, retirement pensions, and medical care, and they allocate such benefits largely according to seniority. Consequently, a senior fellow may be eligible for a three-bedroom apartment, while a fellow may only qualify for a two-bedroom apartment. Naturally this system creates great incentives for researchers to seek promotion through publishing journal articles, preferably as a single or lead author.

Publishing scientific articles is one metric of research output; generating technologies that are commercially successful is another. In 1993, the State Science and Technology Commission and State Reform Commission proposed new guidelines in the wake of financial decentralization under the title "Some Opinions on Staff Management, Structural Adjustment, and In-Depth Reform" (see Wang 2000). The document recommended that research institutions respond to market signals by producing outputs with more immediate economic consequences. The document also encouraged research institutes to generate revenues from development

Table 3.11 China: Composition of JAAS personnel, 1988–98

Year	Research staff	Support staff	Business staff	Retirees	Total: Excluding retirees	Total: Including retirees
1988	1,105	1,691	164	743	2,960	3,703
1989	1,058	1,653	201	774	2,912	3,686
1990	1,067	1,649	216	839	2,932	3,771
1991	1,104	1,584	219	854	2,907	3,761
1992	1,131	1,573	179	914	2,883	3,797
1993	1,137	1,466	165	1,078	2,768	3,846
1994	1,216	1,412	214	1,148	2,842	3,990
1995	1,206	1,404	230	1,207	2,840	4,047
1996	1,163	1,387	240	1,277	2,790	4,067
1997	1,084	1,381	264	1,357	2,729	4,086
1998	1,114	1,259	393	1,447	2,766	4,213
Percentage change, 1988–98	0.8	–25.5	139.6	94.8	–6.6	13.8

Source: Jiangsu Academy of Agricultural Sciences, various years.

and other commercial activities. The original aim of this reform was to subsidize R&D with revenues from businesses, but many institutes passed on their development revenues to staff members, leaving little for R&D. Nevertheless, commercialization has become a major feature in Jiangsu's agricultural R&D system.

Personnel. Several features are apparent from Table 3.11. First, the number of JAAS research staff changed little between 1988 and 1998: numbers rose from 1,105 in 1988 to 1,216 in 1994, then dropped to 1,114 in 1998. Second, responding to policy reforms, the number of managerial and support staff was cut by about 26 percent. At the same time, the number of employees involved in activities generating business income more than doubled, from 164 to 393. Third, with an aging population of researchers, the number of retirees rose from 743 to 1,447.

Excluding retirees, the total number of full-time employees at JAAS was 2,766 in 1998, a decline of 6.6 percent from 1988. Including retirees, however, the number of staff on the payroll increased by 13.8 percent from 3,703 to 4,213, with researchers accounting for only 26.4 percent of the 1998 total.

Funding and expenditures. Core government funding increased more than threefold from 1988 to 1998, from 9.2 million to 37.7 million yuan, evaluated at 1988 constant prices (Table 3.12). Project funding fluctuated around 4.5 million yuan for the first half of the 1990s, then increased significantly in 1997 and 1998.

Table 3.12 China: Major JAAS revenue and expenditure shares, 1988–98

Category	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Major revenues (constant 1988 yuan, millions)											
Core	9.2	8.9	9.6	10.3	11.1	10.6	18.9	19.7	22.8	29.5	37.7
Project funding	4.9	5.4	6.0	4.1	4.7	4.2	4.1	4.0	4.8	6.3	8.0
Net development income	1.1	2.3	2.9	3.8	4.6	5.3	5.7	6.2	10.1	12.8	14.2
Major expenditures (constant 1988 yuan, millions)											
Wages	10.2	8.9	9.8	13.1	11.9	15.7	17.4	16.8	23.4	29.8	35.4
R&D	6.4	4.1	4.5	9.2	5.4	7.1	2.3	2.3	4.3	10.6	12.2
Development	10.3	5.7	5.2	11.1	13.0	24.3	22.4	20.4	44.1	47.0	47.1

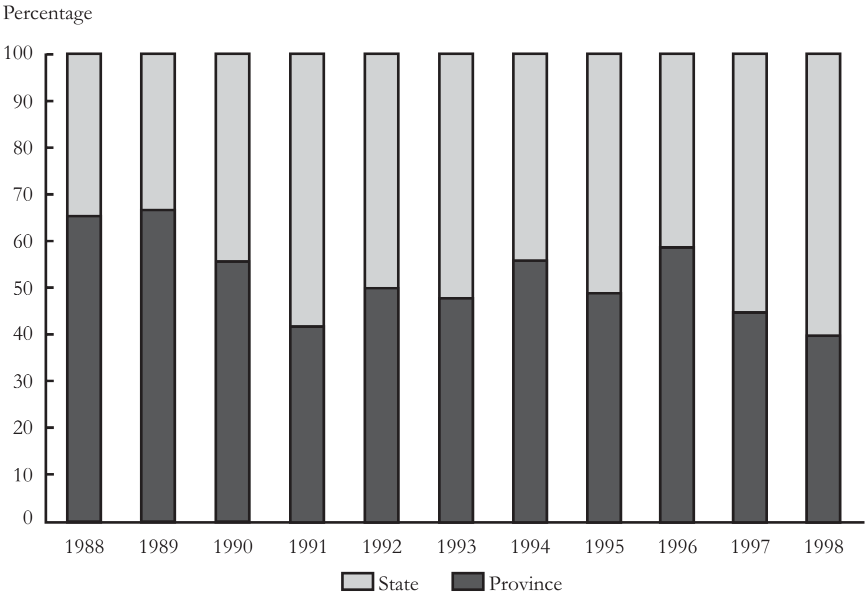
Source: Jiangsu Academy of Agricultural Sciences, various years.

With increased commercialization, net income from business activities rose sharply, from 1.1 million to 14.2 million yuan over the same period.

In terms of expenditure, core funding was used largely to finance wages; hence the two sets of data show similar upward trends between 1988 and 1998, in response to the growth of retiree numbers. JAAS expenditure declined from 6.4 million yuan in 1988 to 2.3 million yuan by 1995, then soared to 12.2 million yuan by 1998, when the government pumped significant new funding into the agricultural R&D system following the large spike in grain imports in 1994 and 1995. Development expenditures increased markedly, from 10.3 million to 47.1 million yuan. Because of the incentive mechanisms that directly link staff incomes—particularly staff bonuses—with business revenues, researchers, managerial staff, and support staff all benefit from profit-making research activities.

In line with the national trend toward decentralizing government services, JAAS became increasingly dependent on funding from within the province rather than from the central government (Figure 3.3). In 1988, state funding accounted for over 70 percent but by 1998 dropped to less than 50 percent. Because Jiangsu is one of the richest provinces, it was able to supplement its shrinking share of state

Figure 3.3 China: JAAS funding sources, 1988–98



Source: Jiangsu Academy of Agricultural Sciences, various years.

Table 3.13 China: Average size of JAAS research projects, 1988–98

Year	Research funding per capita	Number of researchers per project
1988	5.8	2.5
1989	3.9	2.2
1990	4.3	1.7
1991	8.3	1.6
1992	4.8	1.6
1993	6.2	1.6
1994	1.9	1.6
1995	1.9	1.5
1996	3.7	1.6
1997	9.8	1.5
1998	10.9	1.4

Source: Jiangsu Academy of Agricultural Sciences, various years.

funding. But in many poorer provinces, agricultural research institutions face more severe budget restrictions (Fan, Zhang, and Zhang 2004).

Size of research projects. Table 3.13 indicates the scale of research activities through funding per researcher and the average number of researchers per project. Because the total number of full-time researchers remained relatively stable, funding per researcher closely correlates with total funding, decreasing dramatically from 1988 to 1995 and increasing thereafter. The average number of researchers per project fell from 2.5 in 1988 to 1.4 in 1998, indicating minimal researcher collaboration. This trend is largely the result of the emphasis on first authorship in professional evaluation and promotion; however, achieving results with far-reaching significance will be particularly challenging with the majority of researchers now undertaking such small-scale research projects. In informal interviews with researchers, most expressed concern that the current incentive system inhibited larger-scale cooperative research projects, which are perceived as more uncertain in terms of funding, promotion and recognition, and outputs.

Research performance. Changes in funding sources and incentive mechanisms also affect research outputs (Table 3.14). The benefits of sole authorship are reflected in the dramatic increase in the number of published papers and books. At the same time, large peer-reviewed research outputs, indicative of more significant, long-term projects, declined from 70 to 42.

Awards, and royalties for papers and books, can serve as an intermediate indicator of the productivity of research staff. Figure 3.4 plots research productivity based

Table 3.14 China: JAAS research output, 1988–98

			Other peer-reviewed outputs		Prizes[c]		
Year	Papers	Books	Evaluated variety[a]	Prize-winning[b]	State 1 and 2	Province 1 and 2	Model demonstration plots[d]
1988	546	2	70	76	1	14	535
1989	636	14	68	82	3	5	675
1990	674	18	111	75	1	21	1,018
1991	648	17	57	97	2	10	661
1992	619	20	75	71	5	18	859
1993	701	17	43	69	4	9	709
1994	581	15	55	59	0	10	1,207
1995	608	21	48	43	2	5	685
1996	497	27	36	80	1	15	846
1997	605	15	44	65	5	12	761
1998	652	21	42	75	3	13	709

Source: Jiangsu Academy of Agricultural Sciences, various years.

[a] Indicates released crop varieties subject to evaluation.

[b] Indicates that the research output has won a peer-reviewed prize.

[c] Includes class 1 and class 2 prizes awarded by state and provincial agencies.

[d] Represents the number of demonstration plots established for side-by-side comparisons of new and old crop varieties or to demonstrate new agricultural technologies to farmers.

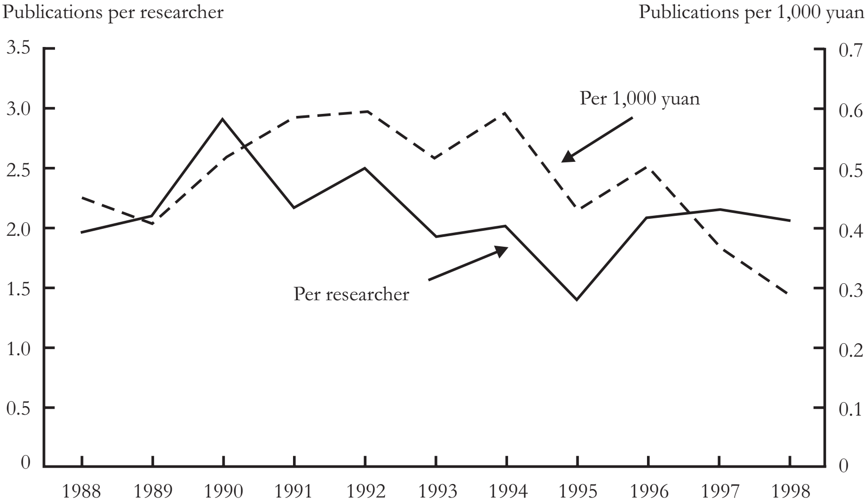
on labor and investment input. The first indicator is output value per researcher, and the second is output value per 1,000 yuan of input. Both indicators show that productivity has changed little during the survey period despite the increase in overall funding to JAAS.

Given that one of its original purposes was to supplement government funds for R&D, commercialization has been successful. However, research output (at least to the extent revealed by publication and related measures) has changed little, suggesting that the commercial revenues have not significantly increased the funds used for R&D, as originally envisioned.

A Prospective Look at China's Research Reforms

Agricultural research has played a key role in meeting the national food demand and reducing poverty, as many studies have shown (Alston et al. 2000; Fan 2000; Fan, Zhang, and Zhang 2004). However, much remains to be achieved. China's demand for agricultural products will continue to expand (in terms of both the quantity and quality of products and shifts in the composition of food, feed, and

Figure 3.4 China: Publication performance of JAAS researchers, 1988–98



Source: Compiled by authors.

fiber demands) in ways that remain heavily reliant on improvements in productivity. How China's agricultural research system responds to these demands will be critical; so will the research policies that can help or hinder these developments.

Increasing Public Investment in Agricultural Research

A further increase in investment in agricultural R&D is needed. Despite its comparatively rapid overall growth, China's agricultural R&D spending—relative to the size of the agricultural sector it serves—lags well behind that of many other countries. But do significant scale and scope economies go unrealized as a result of the parallel national, provincial, and prefectural systems? As of 2002, agricultural research expenditure as a percentage of agricultural GDP averaged around 0.50 percent, well below the corresponding developed-country average and even lower than in most developing countries (which averaged 0.62 percent). Various evidence shows that agricultural research investment not only yields high economic returns but also significantly reduces rural poverty and regional income inequality (Fan 2000). Moreover, according to recent evidence, agricultural research has contributed to a large drop in urban poverty by lowering food prices (Fan, Fang, and Zhang 2003). Absent agricultural research, China would have many more urban poor today. Finally, increased agricultural research investment is one of the most efficient ways to solve China's long-term food-security problem (Huang, Rozelle, and Rosegrant 1999). All these factors suggest that increased investment in agricultural research is a "win–win–win" (growth–poverty and equity–food security) national development strategy.

Reforming the Public Research Institutes

After more than 15 years of reform, the Chinese public agricultural research system now faces new challenges. The coexistence of public research and commercial activities has played an important role in mobilizing resources to support agricultural research and in enhancing the link between agricultural research and those who ultimately use its outputs. As the system evolves, however, these symbiotic activities are often in conflict because public agricultural research aims to provide public goods and carry out basic, strategic, and not-for-profit research, whereas revenue-generating businesses provide private goods and engage in commercial activities. Hence, the two operations would likely benefit from even more distinct and separate institutional arrangements. A more focused, efficient, and effective research system is urgently needed to achieve the multiple goals of agricultural growth, food security, and poverty reduction. The commercial activities, which are not always compatible with these goals, need to be hived off from the public research agencies.

On the one hand, the government should increase its investment in public research; on the other, the current public research institutes need further reform. The major (and interrelated) problems currently confronting most of the research institutes are overstaffing, the heavy financial burden imposed by retirees, the lack of an effective incentive system, and lack of coordination between national and regional research institutes.

To avoid overstaffing, all research and administrative positions should be created on the basis of need, and all positions should be filled though public announcements and open competition. Redundant staff should be encouraged to retire and provided assistance in seeking employment elsewhere. The reform of the agricultural research system should be considered in the larger social and financial context. These challenges are largely similar to the problems of the state-owned enterprises (SOEs). Hence, some of the future reforms required for research are likely to proceed in step with the overall economic and institutional reforms of China's SOEs. Several schemes to reform the Chinese pension system have been proposed. For example, current and newly hired staff could be required to contribute a share of their salary to a retirement account, while contributions for retired staff could be covered by government funds. Incentive structures for researchers should be performance based. Promotion and annual salary increases should be based on more rigorous performance assessment.

The current organizational structure for agricultural research strictly parallels the country's administrative system rather than being based on agroecological or other relevant considerations. In Gongzhuning City, Jinglin Province, for example, the provincial academy of agricultural sciences and a prefectural agricultural research institute both carry out R&D on maize. Similar duplications exist in almost all provinces in China. If research resources are to be allocated more efficiently and appropriately across agroecological zones, professional linkages and coordination between institutes at different levels must be improved. One solution would be to merge institutes with similar mandates within agroecological zones—particularly within cities.

Private versus Public Research

In recent years, the focus has been on privatizing the funding for publicly performed research rather than privatizing research per se. Several factors have contributed to this trend. A high proportion of the agricultural research carried out by the Ministry of Agriculture's agencies is directed toward production. But if China continues to develop as it has over the past decade, the demand for agricultural technologies will increasingly move off-farm. Further increases in the use of off-farm inputs in agriculture, such as fertilizers, pesticides, and machinery, will stimulate increased demand for new technologies and know-how aimed at the input supply sector. Rising per capita incomes are resulting in a rapid increase in the demand for processed agricultural products; this in turn will stimulate the demand for postharvest technologies related to the storage, processing, packaging, and marketing of agricultural produce. China's existing research capacity in input supply and, particularly, postharvest technology is embryonic. Private research could fill much of this gap, given that much of the required technological and market development is more amenable to private initiatives.

Considering the increasing fiscal constraints facing the Chinese national agricultural research system, multinational agribusiness and R&D firms can be called upon to play a greater role in the growth of Chinese agriculture. But this will not happen spontaneously. A number of significant policy and administrative changes are needed to improve the environment for these firms before they are likely to play a larger role. These include strict and transparent enforcement of IPR protection for agrochemicals, veterinary pharmaceuticals, plant and animal genetics and biotechnology, and other agricultural technologies, to reassure investors that theft of proprietary technology will not be tolerated. The legal framework is in place, but its enforcement remains uncertain (Koo et al. 2003). The restrictions on foreign direct investment in improving grain, oilseed, and cottonseed varieties also need to be removed. These restrictions have hindered investment and technology transfer and prevent Chinese farmers from accessing the newest internationally developed seed varieties. The current policy also requiring that Chinese partners must have a majority share in domestic marketing enterprises makes transnational firms reluctant to manufacture high-technology products because they cannot control product distribution. Firms that manufacture agricultural inputs need the opportunity to market their products directly to farmers. Market competition would improve distribution efficiency.

Regulations dealing with foreign direct investments by transnational firms should be more transparent. Domestic taxation schedules, import tariffs, and foreign exchange rules are adequately defined. However, application and approval procedures are complex, requiring separate negotiations with officials in each province in which investment and operations are proposed. There is also a problem of changing the rules after investments have been made: while such changes may be necessary for equity or other reasons, provision should be made for grandfathering the foreign enterprises over an adjustment period.

The Chinese agricultural research system has experienced dramatic change over the past several decades and now represents one of the world's largest public agricultural R&D institutions. For the past 15 years, the system has also pursued an aggressive reform agenda and has achieved substantial success. However, further reforms are still required to transform the system into a modern and efficient powerhouse propelling Chinese agriculture into the new century.

Appendix Table 3A.1 China: Agricultural research expenditures, 1961–2002

Year	Current prices (million yuan)	1999 prices (million yuan)	1999 prices (million international dollars)
1961	199.3	630.9	336.5
1962	142.3	456.2	243.3
1963	190.8	623.6	332.5
1964	247.3	802.9	428.2
1965	276.0	876.7	467.6
1966	254.7	822.9	438.9
1967	157.4	505.2	269.4
1968	151.9	481.3	256.7
1969	245.3	807.6	430.7
1970	303.2	1,025.5	546.9
1971	280.7	943.2	503.0
1972	365.4	1,227.9	654.8
1973	350.6	1,176.5	627.4
1974	351.7	1,177.4	627.9

(*continued*)

Appendix Table 3A.1 (continued)

Year	Current prices (million yuan)	1999 prices (million yuan)	1999 prices (million international dollars)
1975	408.6	1,384.1	738.1
1976	399.9	1,357.2	723.8
1977	425.0	1,426.9	761.0
1978	546.2	1,809.7	965.1
1979	641.3	2,051.9	1,094.2
1980	667.5	2,057.7	1,097.3
1981	639.4	1,926.8	1,027.5
1982	657.1	1,983.8	1,057.9
1983	827.9	2,473.2	1,318.9
1984	990.6	2,821.3	1,504.5
1985	1,077.4	2,785.8	1,485.6
1986	1,140.5	2,819.2	1,503.5
1987	1,126.5	2,650.4	1,413.4
1988	1,476.4	3,098.0	1,652.1
1989	1,703.9	3,286.0	1,752.4
1990	1,627.6	2,970.3	1,584.0
1991	1,862.1	3,183.8	1,697.9
1992	2,357.7	3,736.0	1,992.4
1993	2,809.9	3,887.0	2,072.9
1994	3,596.7	4,149.5	2,212.9
1995	4,049.8	4,128.2	2,201.5
1996	4,450.2	4,283.0	2,284.1
1997	4,145.4	3,957.2	2,110.3
1998	4,804.1	4,698.7	2,505.8
1999	4,895.0	4,895.0	2,610.4
2000	5,841.5	5,787.0	3,086.1
2001	NA	NA	NA
2002	7,958.6	7,837.0	4,179.4

Sources: Data compiled by authors from Fan and Pardey 1992, 1997; State Statistical Bureau, various years; and State Science and Technology Commission, various years.

Note: Expenditures include spending by relevant institutes from all levels of governments and agricultural research spending in the universities. NA indicates data are not available.

Notes

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1. The impact of and returns to research investment in Chinese agriculture have been measured by numerous scholars, including Huang and Rozelle (1996); Fan and Pardey (1997); Huang, Rozelle, and Rosegrant (1999); Fan (2000); and Fan, Zhang, and Zhang (2004).

2. The U.S. system spends more in total (that is, from both public and private sources) on agricultural R&D but employs fewer scientists. Measured in terms of new knowledge and technologies produced versus resources committed to research, the U.S. system is most likely considerably larger.

3. The population growth rate was 1.6 percent per year between 1952 and 2000.

4. The contribution of productivity increases comes from technical change, technical efficiency improvement, and allocative efficiency improvement.

5. Rozelle, Pray, and Huang (1999) argue that foreign technology transfer has played a key role in promoting agricultural productivity for the past several years and can continue to do so, given greater transparency in government regulations and greater security in property rights generally and, specifically, those applying to technologies.

6. Unlike most developed countries, China has yet to develop national pension and social-security systems; thus the institutes are required by the government to provide a pension, housing, and medical care coverage to all their retirees.

7. A survey of all research institutes at the Jiangsu Academy of Agricultural Sciences (JAAS) was conducted jointly by IFPRI, CAAS, and JAAS in August and September 2000. The survey, which included 15 provincial and 9 regional institutes for the period 1988–98, compiled details on personnel, expenditures, funding sources, and research achievements. The 15 provincial research units consisted of the headquarters, research center, training center, veterinary institute, horticulture institute, food institute, modernization institute, grain crop institute, fertilizer institute, genetic institute, vegetable institute, plant protection institute, cash crop institute, and information institute. The 9 regional institutes were Xuzhou, Huaiyin, Taihu, Yanjiang, Yanhai, Lixiahe, Zhenjiang, Nanjing, and Lianyungang.

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Chapter 4

Indonesia: Coping with Economic and Political Instability

Keith O. Fuglie and Roley R. Piggott

Introduction

Broad Characteristics of the Indonesian Economy

Indonesia is a Southeast Asian archipelago consisting of some 17,500 equatorial islands (6,000 of which are inhabited) stretching in an east–west direction over 5,000 kilometers. It has a land area of 1.83 million square kilometers; in 2000 this supported a population of 203.5 million (the fourth largest in the world), which is growing at about 1.4 percent per annum. While the overall population density is about 111 persons per square kilometer, 59 percent of the population lives on the island of Java, which has a population density of 944 persons per square kilometer. The overall ratio of urban to rural population was about 40:60 in 1999 (22:78 in 1980).

The Asian financial crisis that began in 1997 affected Indonesia severely: its economy shrank by around 15 percent between 1997 and 1998. Since then, modest growth has resumed, but at substantially lower growth rates than those recorded in the decades prior to the crisis. The global rankings published in the *World Development Report for 1999* (World Bank 2001) placed Indonesia 143rd of 206 economies in terms of real gross national product (GNP) per capita.

The extent of structural changes in the Indonesian economy between 1965 and 2003 is shown in Table 4.1. The population doubled. Real GDP increased by about 900 percent and real per capita income by about 440 percent. Large changes have occurred in the sectoral shares of GDP, with agriculture's share declining from

Table 4.1 Indonesia: Structural changes in the economy, 1965–2003

Indicator	1965	1975	1985	1995	2000	2003
Population (millions)	104.6	132.6	163.0	192.8	206.3	214.7
Gross domestic product (billions of 1999 international dollars)	75.2	148.4	285.8	588.9	609.7	680.9
Percentage of GDP						
Agriculture	56.0	30.2	23.2	17.1	17.2	16.6
Mining, oil, and gas	31.4	36.3	40.9	41.1	36.7	39.9
Manufacturing	8.4	9.8	16.0	24.1	24.9	24.7
Services	4.2	23.7	19.9	17.7	21.2	18.9
Percentage of employment						
Agriculture	69.2	61.6	54.7	44.0	45.3	46.3
Manufacturing	6.9	8.4	9.3	12.6	13.0	12.0
Other	23.9	30.1	36.1	43.4	41.8	41.7
Per capita income (1999 international dollars)	719	1,120	1,753	3,055	2,956	3,172
Exports as percentage of GDP	5.5	24.0	22.2	26.3	42.9	31.2
Imports as percentage of GDP	5.4	21.0	20.4	27.6	33.5	25.7

Source: World Bank 2005.

Note: Percentages do not always sum to 100 given rounding errors.

nearly 60 percent to only 17 percent, accompanied by significant increases in the shares of the services sector (now the dominant sector, with a 40 percent share in 2003), manufacturing (25 percent), and mining, oil, and gas (19 percent). Similar trends have occurred in sectoral employment shares, with agriculture's share declining from nearly 70 percent to 46 percent. The intensity of international trade has increased, with the share of exports in GDP growing from 5.5 percent in 1965 to 26 percent in 2003, and imports as a percentage of GDP growing from 5.4 percent in 1965 to 25.7 percent in 2003.

Broad trends in the agricultural economy from the early 1960s to the early 2000s are shown in Table 4.2. Real agricultural GDP has increased; food-crop production dominates the sector, accounting for half of the total. However, the relative importance of crop production (and of food crops in particular) has declined, and the relative importance of livestock, forestry, and fisheries production has increased. Indonesia possesses the world's second largest area of tropical forest (after Brazil) and among the largest saltwater and coastal fishing grounds.

Rice production dominates the food-crop sector, and production increased fourfold between the early 1960s and the early 2000s, mainly as a result of yield increases. The increased use of modern varieties and fertilizer has been important in securing higher yields. Rice remains the staple food and is of great political importance. After rice, cassava is the next most important food crop, closely followed by maize. Nonfood "estate" crops, such as rubber, oil palm, sugarcane, and cacao, are

Table 4.2 Indonesia: Trends in agriculture, 1961–2003 (annual averages)

Indicator	1961–65	1971–75	1981–85	1991–95	2001–03
Agricultural GDP (millions of 1999 international dollars)	39,049	45,911	60,319	88,689	110,385
Agricultural research (millions of 1999 international dollars)	NA	110.6	208.1	230.1	233.3
Percentage of AgGDP					
Food crops	65.1	59.9	61.8	55.8	50.7
Nonfood crops	17.3	17.1	15.8	16.6	15.5
Livestock	6.6	7.1	9.9	11.4	12.8
Forestry	3.0	10.3	5.7	6.9	6.3
Fisheries	8.0	5.7	6.8	9.3	14.7
Rice output (million tons of paddy rice)	12.4	21.2	35.8	47.5	51.3
Livestock (million head)	10.5	9.9	12.0	16.2	17.4
Total cropland (million hectares)[a]	17.6	18.9	26.0	32.2	39.3
Java and Madura	9.0	8.8	7.0	7.1	7.1
Other islands	8.6	10.0	19.6	25.1	32.2
Number of farm households (millions)	12.2	14.4	19.5	21.7	24.9
Java and Madura	7.9	8.7	11.6	11.8	13.6
Other islands	4.3	5.7	7.9	9.9	11.3
Average size of farm[b] (hectares)	1.1	1.0	1.0	0.8	0.8
Java and Madura	0.7	0.6	0.6	0.5	0.4
Other islands	1.7	1.5	1.6	1.2	1.3
Agricultural research spending (1999 international dollars)					
Agricultural research per farm	NA	7.7	10.7	10.6	9.4
Agricultural research per capita	NA	0.9	1.3	1.2	1.1
Agricultural research as percentage of AgGDP	NA	0.2	0.3	0.3	0.2
Rice yield (kilograms per hectare)	1,761	2,542	3,786	4,352	4,465
Irrigated cropland (percent)[c]	15.2	16.1	17.9	22.8	23.5
Fertilizer use (kilograms per hectare)	6.9	22.7	63.3	73.9	74.3
Agricultural wage (kilograms of rice per day)[d]	1.1	2.7	3.7	4.1	5.9
Agricultural exports as percentage of AgGDP	NA	NA	NA	24	31
Agricultural imports as percentage of AgGDP	NA	NA	NA	16	21

Sources: Agricultural GDP, shares of AgGDP, and agricultural trade are from BPS, *Statistical Yearbook of Indonesia* (annual issues, 1961–95). Rice output, livestock numbers, rice yield, and fertilizer use are from FAO 2005. Cropland, irrigated cropland, and agricultural wages are from van der Eng 1996. Farm numbers and landholdings are from agricultural census for 1963, 1973, 1983 (BPS 1985), 1993 (BPS 1995), and 2003 (BPS 2004). Research expenditures include expenditures by the Agency for Agricultural Research and Development (AARD) and the estate-crop research institutes of the Indonesian Planters Association for Research and Development (IPARD). AARD conducted forestry research until 1982 and fisheries research until 2000. Sources for research expenditures for AARD institutes: 1974–83 from Pardey, Eveleens, and Abdurachman 2000 (Table Appendix 2); 1984–85 from AARD 1991; 1986–92 from AARD 1992b; 1993 from AARD 1994; 1994–95 from AARD 1997; 1996–98 from AARD 1999b; 1999–2000 from AARD 2003. Sources for research expenditures by IPARD institutes: 1974–83 from Pardey, Eveleens, and Abdurachman 2000 (Table Appendix 2); 1984–85 government contribution from Pardey, Eveleens, and Abdurachman 2000, and member contribution from AARD 1990; 1986–88 from AARD 1992b; 1989–2000 from R. Sumitro, personal communication, 2001. A major source of funds (around 75 percent in 1998) for IPARD institutes is product sales, but these data are available only from 1989 onward. Revenue from product sales was estimated for 1974–88 using a constant revenue per scientist ratio (1989–2000 average in constant 1999 rupiahs).

Notes: Percentages do not always sum to 100 given rounding errors. NA indicates data are not available.

[a] Includes land in annual (paddy, garden, and upland crops) and perennial (estate) crops. Only data for 2001 and 2002 were available for estimating average agricultural land during 2001–3.

[b] Represents farm household landholdings and does not include land in perennial or estate crops.

[c] Represents percentage of cropland planted to annuals receiving irrigation at least part of the year.

[d] Represents wages of male plantation workers on Java.

becoming an increasingly important component of Indonesia's agricultural sector.[1] Livestock production is also growing rapidly in response to the rising demand for animal protein, commensurate with rising per capita incomes.

Although little new land is available for cropping on Java, there has been a steady increase in the area of land cropped on other islands. Total agricultural cropland (including land in perennial or estate crops) grew from 17.6 million hectares in the early 1960s to 37.4 million hectares by 2002. According to the Indonesian agricultural census (done every ten years since 1963), the number of farm households steadily increased nationwide between 1963 and 2003. The agricultural census also reports landholdings by farm households (these estimates mainly refer to annual cropland and exclude land in perennial crops, even though smallholders are major producers of most estate crops). According to census figures, the average farm size has been decreasing, to about 0.4 hectares per household in Java and 1.3 hectares per household outside Java.

Spending for agricultural research was very low in the 1970s, but real spending per farm and per capita had doubled by the 1980s. Nevertheless, Indonesia ranks near the bottom among Asian countries in agricultural research spending relative to agricultural GDP (Pardey, Roseboom, and Fan 1998).

The Indonesian Agriculture Success Story

Much has been written about Indonesia's success in raising agricultural production, particularly rice, over the past three decades. Indonesia went from being the world's largest rice importer in the mid-1960s to becoming nearly self-sufficient by the mid-1980s (Jatileksono 1987). But agricultural growth in Indonesia has not been limited to rice. Since Indonesia adopted a more outward orientation in 1985, its exports of agricultural commodities have grown substantially. Agricultural exports as a share of agricultural GDP increased from 16 percent in 1985 to nearly 30 percent a decade later (Erwidodo 1999). By the mid-1990s, Indonesia emerged as the world's second largest exporter of rubber and oil palm and the third largest exporter of cacao and coffee. The value of shrimp exports also grew dramatically over this period, surpassing everything but rubber as an agricultural export earner. Imports of agricultural products grew at an even more rapid rate (Erwidodo 1999).

Table 4.3 elaborates on some of the data provided in Table 4.2, tracing the major changes in agricultural production and input use in Indonesia between 1961 and 2000.[2] Quantities produced are shown in million metric tons of "rice equivalents" in value terms, meaning that commodity prices are normalized on the price of rice in a given year. The average growth in agricultural production over this period was 2.9 percent per annum, with total output rising from 50.5 million metric tons per year in the early 1960s to 137.1 million metric tons per year by the

Table 4.3 Indonesia: Changes in agricultural production and input use, 1961–2000

	Average quantity (millions of tons of rice equivalents)				Average annual growth rate (percent)			
Production/inputs	**1961–65**	**1971–75**	**1981–85**	**1991–95**	**1961–67**	**1968–92**	**1993–2000**	**1961–2000**
Agriculture outputs, total	50.50	65.60	94.46	137.12	0.66	4.04	1.04	2.90
Crop and animal outputs, total[a]	35.34	48.93	75.63	112.75	1.11	4.72	1.20	3.44
Food crops, all	19.73	28.74	45.91	62.33	1.20	5.01	0.43	3.48
Rice, paddy	12.39	21.18	35.77	47.50	1.74	5.50	0.75	3.94
Cassava	2.48	2.42	2.79	3.39	–0.51	1.94	0.16	1.20
Maize	1.69	1.75	2.71	4.33	9.71	7.68	2.54	6.94
Horticultural crops, all	3.21	4.51	5.55	8.68	2.72	3.52	4.20	3.54
Fruits, all	1.43	2.04	2.86	3.81	2.43	3.49	5.69	3.78
Vegetables, all	1.78	2.47	2.68	4.87	2.97	3.90	3.89	3.75
Nonfood crops, all	9.05	11.10	16.38	27.18	0.63	4.32	2.67	3.41
Cane sugar	0.84	1.17	1.96	2.93	1.35	5.59	–4.12	2.95
Rubber	1.68	1.93	2.38	3.45	0.41	2.85	1.80	2.26
Palm oil	0.19	0.38	1.24	4.37	2.59	12.75	10.16	10.65
Animal products, all	3.34	4.57	7.79	14.56	1.48	5.66	0.67	4.00
Meat	3.04	4.18	6.67	12.41	1.62	12.63	3.87	3.75
Milk and eggs	0.30	0.39	1.12	2.15	0.14	8.15	3.46	5.95
Fish products, all	2.91	3.89	6.42	11.12	4.61	4.41	4.27	4.41
Forest products, all	12.26	12.78	12.41	13.25	–1.49	0.74	–3.54	–0.48
Agricultural inputs								
Cropland (million hectares)	17.55	18.91	26.02	32.25	0.52	2.34	1.93	1.97
Area harvested (million hectares)	17.52	19.62	22.66	28.35	0.81	2.43	0.99	1.88
Irrigated cropland (million hectares)	2.42	2.66	3.31	4.56	1.44	2.34	0.30	1.78
Agricultural labor (million workers)	28.61	31.70	37.55	46.01	0.70	1.66	1.04	1.39
Fertilizer (million tons/year)	0.12	0.43	1.67	2.46	1.65	16.04	0.13	10.56
Agricultural machinery (million horsepower)	0.07	0.16	0.19	0.58	7.45	14.31	5.88	11.52
Animals (million head of stock)	14.00	13.59	18.41	30.99	–0.01	3.37	–0.26	2.10

Source: These data are from Fuglie (2004), who analyzed agricultural productivity growth in Indonesia from 1961 to 2000.

Notes: The first four columns show average annual figures for the first half of each decade from the 1960s to the 1990s. The second four columns report growth rates for each series over the entire period of this study (1961–2000) and during three periods of Indonesia's agricultural development.

[a] Net of seed and feed.

early 1990s. Rice production itself grew by nearly 4 percent per annum. Average annual growth rates for animal and fish products also exceeded 4 percent during these four decades.

In Table 4.3 we also show the performance of Indonesia's agriculture during three periods: 1961–67, a period of political and economic instability in Indonesia; 1968–91, when agricultural output and productivity grew rapidly); and 1993–2000, when agricultural productivity growth appeared to stagnate. During the first period, agricultural output grew by only 0.7 percent per year, but this growth was mostly resource-based and correlated closely with the increase in agricultural land and labor. Productivity growth played a major role in accelerating agricultural growth, which increased by more than 4 percent per annum during the second period. The third period includes the Asian financial crisis that began in 1997. The El Niño phenomenon also caused a significant drought in 1997–98, which caused crop production to fall. Overall growth in agricultural output since 1993 has averaged about 1 percent per year, roughly matching the rate of growth in agricultural resource use, a pattern which suggests that there was once again little or no improvement in overall agricultural productivity. Further, although the Asian financial crisis and El Niño had strong negative effects on the Indonesian agriculture sector, a slowdown in agricultural productivity growth is evident even before these events.

The intensification of agricultural growth between 1968 and 1992 was broad-based, affecting not only food-crop production but also horticulture, estate crops, and livestock production. Between 1968 and 1992, when productivity growth accelerated, annual growth rates in production exceeded 4 percent for rice, maize, non-food crops, animal products, and fish products. During these years, yield improvements from Green Revolution technologies (especially new varieties and fertilizers) were particularly important in rice and, to a lesser degree, in maize and other crops. From 1993 to 2000 agricultural production growth fell to 1.0 percent per year. The animal subsector, which relies heavily on imported feed, was particularly hard hit by the Asian financial crisis and the resultant devaluation of the rupiah.

Much of the growth in production that occurred between 1961 and 2000 can be accounted for by increases in conventional inputs, such as cropland, labor, and fertilizers. However, for long-term sustainability of growth in agriculture, productivity gains are more important. In Table 4.4 we show estimates of a total factor productivity (TFP) index developed by Fuglie (2004). This index shows that TFP grew by about 0.77 percent per annum in the early 1960s but then increased to 2.56 percent per annum between 1968 and 1992. The drop in TFP between 1993 and 2000 reflects a number of factors, including a drought-induced decline in crop production, an economic recession, fewer workers exiting agriculture, and expansion of cropland into more marginal areas. It appears that once the initial gains of

Table 4.4 Indonesia: Agricultural productivity growth, 1961–2000

	Average annual growth rate (percent)			
Indicator	**1961–67**	**1968–92**	**1993–2000**	**1961–2000**
Total outputs (crop and animal)	1.25	4.79	1.12	3.49
Total inputs	0.48	2.24	1.19	1.75
Total factor productivity	0.77	2.56	–0.07	1.74
Labor productivity (output per worker)	0.33	2.95	0.07	1.96
Land productivity (output per unit of cropland)	0.78	2.38	–0.93	1.45
Land area per worker	–0.45	0.60	1.02	0.52
Food crop output per capita	0.18	4.04	–0.39	2.54
Rice output per capita	0.97	3.70	–0.35	2.45

Source: These data are from Fuglie 2004. See source note to Table 4.3 for more details.

the Green Revolution were exhausted, public and private investment in agriculture were not sufficient to sustain the supply of new technology to the sector.

Table 4.4 also shows changes in some indicators of food security (food and rice output per capita) and partial productivity (output per worker and output per unit of cropland). Indonesia's success in enhancing food security is illustrated by the impressive growth in per capita food production (an average of 2.54 percent per annum from 1961 to 2000). Per capita food production has fallen since 1993, however. Within the agricultural sector, output per worker grew by nearly 2 percent, and output per unit of cropland increased by 1.45 percent per year from 1961 to 2000. Cropland per worker employed in agriculture continued to expand throughout the 1970s, 1980s, and 1990s, with virtually all the expansion occurring outside Java.

The acceleration of growth in TFP from the 1970s corresponds to the period in which investment in agricultural research in Indonesia was substantially increased. But a number of other factors also contributed to the increase: investments in irrigation, improvements in the quality of the agricultural labor force (through rural education), agricultural price policies, government-led food-crop "intensification" programs, and trade and investment liberalization (Jatileksono 1996; van der Eng 1996; Erwidodo 1999). Between 1970 and 2003, government development expenditures for agriculture first increased and then declined relative to agricultural GDP (Table 4.5).[3] Government expenditures for agriculture also declined as a share of total development expenditures, especially after 1989. Expenditures on fertilizer subsidies accounted for a large share of public expenditures for agriculture throughout much of this period, although the fertilizer subsidy was eliminated after 1999.

These national averages above mask important regional differences, especially between land-scarce Java and relatively land-abundant islands like Sumatra,

Table 4.5 Indonesia: Government development expenditures for agriculture, 1970–2003 (million 1999 international dollars)

Year	Total development expenditures for all sectors	Development expenditures for agriculture and natural resources					Agricultural shares (percent)		
		Total	Agriculture and forestry	Irrigation	Fertilizer subsidy	Environment	Agriculture's share of total development expenditures	Agricultural development expenditures as a share of AgGDP	AgGDP as a share of total GDP
1970	3,485	955	486	400	69		27.4	2.1	47.2
1971	4,886	1,164	849	300	14	NA	23.8	2.5	44.8
1972	4,890	1,246	777	395	73	NA	25.5	2.7	40.2
1973	5,516	1,240	635	347	259	NA	22.5	2.5	40.1
1974	5,699	1,671	952	286	433	NA	29.3	3.8	32.7
1975	10,933	5,986	3,089	344	2,554	NA	54.8	13.2	31.7
1976	13,765	3,865	2,013	518	1,335	NA	28.1	8.2	31.1
1977	17,863	4,027	2,454	640	933	NA	22.5	7.8	31.1
1978	17,133	3,460	2,090	928	441	NA	20.2	6.5	30.5
1979	15,195	3,166	1,997	679	491	NA	20.8	5.9	28.1
1980	18,217	3,967	1,952	902	567	545	21.8	7.7	24.8
1981	24,311	6,199	3,546	880	1,165	608	25.5	11.1	25.3
1982	26,889	6,569	3,395	1,018	1,439	717	24.4	10.8	26.3
1983	24,960	5,898	2,835	980	1,425	658	23.6	9.3	26.4
1984	30,675	5,443	2,581	846	1,418	598	17.7	8.6	22.7
1985	29,523	8,575	4,343	1,379	2,170	682	29.0	12.9	23.1

1986	31,305	6,049	2,574	1,402	1,373	700	19.3	8.5	24.1
1987	20,951	4,282	2,072	601	1,174	435	20.4	5.9	23.3
1988	21,936	7,159	4,062	884	1,750	463	32.6	9.0	24.1
1989	25,781	4,764	2,761	1,109	421	473	18.5	5.7	23.6
1990	27,025	6,400	3,944	987	543	926	23.7	7.8	21.5
1991	29,125	5,310	2,906	1,388	476	540	18.2	6.6	19.7
1992	34,070	5,883	3,171	1,629	515	569	17.3	6.8	19.5
1993	35,851	5,497	2,909	1,715	274	599	15.3	6.3	18.5
1994	36,625	5,453	2,846	1,629	385	594	14.9	5.7	17.3
1995	40,549	5,211	1,308	2,229	1,077	597	12.9	5.1	17.1
1996	34,991	4,627	1,342	2,483	174	629	13.2	4.3	16.7
1997	38,828	4,765	1,398	2,502	201	664	12.3	4.4	16.1
1998	22,859	3,195	902	1,559	326	409	14.0	3.0	18.1
1999	35,864	8,014	3,955	2,523	1,123	412	22.3	7.1	19.4
2000	37,275	4,290	2,196	1,650	0	444	11.5	4.1	19.4
2001	53,390	3,017	1,355	1,359	0	303	5.7	2.8	20.4
2002	56,358	3,278	1,506	1,507	0	265	5.8	2.9	21.4
2003	70,658	3,813	1,803	1,816	0	195	5.4	3.4	22.4

Sources: Expenditures for 1970–92 from Government of Indonesia 1974, 1979, 1984, 1989, 1995; expenditures for 1993–2003 from BPS, *Statistical Yearbook of Indonesia* (annual issues, 1970–2003); rupiahs were converted to international dollars using a purchasing power index from World Bank 2005; and the GDP deflator is from International Monetary Fund 2001.

Notes: NA indicates data are not available. Development expenditures do not include routine expenditures for government personnel or capital maintenance.

Kalimantan, and Sulawesi. Differences in regional agricultural productivity changes are discussed in Booth 1988 and van der Eng 1996. This is an important topic for future research on agricultural productivity in Indonesia.

Estimates of productivity growth in Indonesian agriculture are limited because the environmental costs of agricultural development have not been taken into account. Growth in agricultural land area, forest, and fish production have come at some cost to environmental resources, including land degradation, loss of forest habitat, and a decline in water quality, none of which have so far been incorporated into agricultural productivity measurements for Indonesia.

Reality Check: The 1997–98 Crisis

Events since 1997 have afforded a somber reminder of Indonesia's vulnerable food-security situation. A combination of drought, forest fires, the Asian financial crisis, and political upheaval adversely affected the production and distribution of food crops (especially rice) and animal products and exposed large segments of the population to food insecurity. Rice imports reached an all-time high of 4 million metric tons in 1998, more than double the peak level in the 1960s (Kasryno, Nataatmadja, and Rachman 1999). Stringer (1999, pp. 169–70) describes the combination of adverse events and their consequences as follows:

> Indonesia's current socioeconomic crisis has dramatically reversed decades of rapid economic growth, steady progress in poverty reduction, and substantial improvements in food security. Before the crisis began in August, 1997, Indonesia was frequently cited as one of the highest performing Asian economies with per capita GDP growth in the top 10 percent of all developing countries. Since the crisis however, the rupiah's value has dropped precipitously, inflation has soared and GDP has fallen an estimated 14 percent in 1998 (World Bank 1998). The country's poor and those facing food insecurity are especially vulnerable to the falling incomes, increasing food prices, decreases in real wages and rising unemployment and underemployment brought on by these crisis induced events.
>
> Indonesia's capacity to address the crisis has been greatly complicated by forest fires, drought, floods and a sharp decline in crude oil prices. . . . Estimates of the economic damage to Indonesia's logging and timber industries, (excluding environmental and health costs) are set at more than U.S.$900 million (Tay 1998). . . .
>
> A prolonged drought throughout 1997/98 reduced export crop production and, more importantly for the country's food security objectives, contributed to a large drop in paddy production. Initial estimates suggest

> that the 1998 paddy crop is nearly 10 percent below the 1996 production level (FAO 1998; CBS 1999). . . .
>
> Around one-third of the country's population spends 70 percent or more of their total expenditures on food (SUSENAS 1996). Thus, the collapsing demand, rising unemployment, falling food production, increasing food prices and rapidly expanding numbers of malnourished stress the fundamental role agriculture must play in revitalizing the economy.

The crises during the late 1990s led to major changes in agricultural policy in Indonesia. Most important was the reduction in barriers to agricultural trade, including reduction or elimination of tariffs and the elimination of the import monopoly of BULOG (the state trading agency) on major food items such as rice, wheat, and soybeans. Another important result of the crises was that budget austerity measures reduced public spending on agriculture. The long-standing fertilizer subsidy was discontinued in 1999. Funding for agricultural research and extension was also reduced in real terms.

Not all effects of the Asian financial crisis were deleterious for Indonesian agriculture. The resulting devaluation of the rupiah led to a general improvement in the farm–nonfarm terms of trade, as prices of tradable commodities rose faster than prices of nontradable goods and services. Cacao producers in Sulawesi, for example, experienced a windfall as prices in rupiah rose fivefold in a matter of months (Ruf and Cerad-Tera 1999). With the end of the 1997–98 drought, agricultural production in Indonesia recovered in 1999 and 2000. In fact, the value of agriculture to the wider economy was demonstrated by its ability to absorb nonfarm labor displaced by the economic crisis. As a result, unemployment and poverty rates did not increase as much as predicted in some early projections (Manning 2000).

Various policymakers have highlighted the need for an increased agricultural R&D effort to improve Indonesia's food security and meet other long-run development goals. H. S. Dillon, director of the Center for Agricultural Policy Studies in Jakarta, has commented that one of the reasons for the slowdown in technological progress in Indonesian agriculture in recent years (especially when compared with other land-constrained Asian states) is "persistent underfunding of the public sector R&D effort" and claims that "a substantial increase in the real expenditures on agricultural R&D is warranted, given the potential economic and social payoffs likely to result from raising smallholder productivity" (Dillon 1999, p. 12). He is also critical of various features of the Indonesian agricultural research system, including the highly fragmented nature of the agricultural R&D effort, the limited involvement of universities, weak linkages between Indonesia's own R&D effort

Table 4.6 Indonesia: Ministry of Agriculture expenditures by function, 1994–99 (million 1999 international dollars)

Function	1994	1995	1996	1997	1998	1999
Secretary general						
Main office	30.6	219.4	63.2	13.3	32.9	8.5
Regional offices	114.5	119.8	287.0	131.4	187.1	90.6
Quarantine	10.2	10.7	18.2	12.6	12.3	8.5
Foreign office	0.7	0.8	0.8	0.9	0.6	0.9
Mass guidance	108.4	74.1	49.2	42.7	27.2	25.8
Research and development	125.1	131.2	125.5	126.5	76.7	65.7
Education and training	70.5	73.0	70.7	70.9	42.9	41.5
Agribusiness development	0.0	4.8	7.9	7.8	4.5	5.0
Subtotal secretary general	459.9	633.7	622.7	627.7	384.1	322.2
Inspectorate general	4.8	5.2	5.1	4.8	2.9	0.0
Director general, food crops	277.3	243.7	153.0	131.6	76.3	60.7
Director general, plantation	240.7	198.4	118.5	104.3	65.5	0.0
Director general, livestock	84.9	43.9	47.8	49.5	28.8	16.7
Director general, fisheries	122.1	86.0	80.6	72.0	41.9	26.8
Total	1,189.7	1,211.0	1,027.8	989.8	599.4	440.5
Share of total for R&D (percent)	10.5	10.8	12.2	12.8	12.8	14.9

Source: M. Gunawan, personal communication 2003.

Notes: Expenditures include routine and development expenditures. Rupiahs were converted to international dollar denominated currency units using purchasing power parity (PPP) indexes from World Bank 2005.

and those of international R&D providers, disruption of research efforts in the Agency for Agricultural Research and Development (AARD) resulting from a 1995 internal reorganization, and weak intellectual property rights for agricultural technologies.

Recent trends in Ministry of Agriculture (MOA) expenditures for agriculture are shown in Table 4.6. Between 1994 and 1999, routine and development expenditures by MOA declined from $1.19 billion to $440 million in real terms (constant 1999 international dollars). The precipitous decline in public spending on agriculture was part of overall government austerity measures needed to meet a commitment to the International Monetary Fund (IMF) to reduce deficit spending. MOA's spending on agricultural research fell by about half, in real terms, over this period even though research grew as a share of all agricultural expenditures.

Planning for Increased Agricultural Productivity: Challenges and Constraints

Many of the science and technology issues confronting Indonesia's agricultural sector apply to the economy as a whole, such as the need to establish technology competence to effectively absorb new technology from abroad, and to increase international competitiveness through increased productivity rather than low wages.

These issues have featured prominently in Indonesia's science and technology policy (Hill 1995). Agricultural R&D policy has the additional goals of providing food security, reducing rural poverty, and maintaining the quality of natural resources.

While Indonesia substantially increased its science and technology capacity in the 1980s and 1990s, it still remains behind many Asian countries in several important aspects. By the late 1980s, Indonesia's spending for all R&D was less than 0.2 percent of GNP, lower than that of most other countries of Southeast Asia and far below that of industrialized countries such as Japan and Korea (UNESCO 2001). Public spending for education was also low by Asian standards, despite the rapid expansion of the educational system. The enrollment ratio for tertiary education (11.3 percent in 1996), though only half that of Thailand, was in the middle range for developing countries in Asia, as was the share of tertiary students enrolled in science and technology fields (UNESCO 2001).

The State Ministry for Research and Technology (RISTEK) has responsibility for coordinating R&D policy in Indonesia but has little control over the allocation of research expenditures. RISTEK operates a number of competitive grant and other programs for funding research, especially for universities. Budgets for government research institutions are allocated either through ministries or directly to nondepartment agencies. The most important nondepartment research institutions include the Agency for Assessment and Application of Technology (BPPT) for industrial technology, the Indonesian Institutes of Sciences (LIPI) for basic sciences, the Central Statistics Agency (BPS), the National Nuclear Energy Agency (BATAN), and the National Institute for Aeronautics and Space (LAPAN). But agriculture remains the highest priority for government-supported research. AARD in the Ministry of Agriculture is the largest government research agency in Indonesia, with more than 3,000 researchers (Table 4.7). Together with IPARD (estate crops), FORDA (forestry), and the Center for Fisheries, Research and Development (previously part of AARD but transferred to the newly formed Ministry for Marine Resources and Fisheries in 2001), AARD has had by far the largest number of research staff of any government research institution.

The policy direction for agricultural research in Indonesia is articulated in AARD's strategic plans. The 1999–2004 strategic plan describes the main "constraints and challenges" facing the Indonesian agricultural sector. The summary below draws heavily on AARD 1999a (pp. 23–30):

- The industrial and service sectors have not absorbed surplus labor from the agricultural sector to the degree previously anticipated. At the same time, urban migration has occurred as a result of factors such as increased land

Table 4.7 Indonesia: Major government research institutions, 1997

Institution	Affiliation	Research focus	Number of research staff
Agency for Assessment and Application of Technology	Nondepartment agency	Industrial technologies	2,078
Indonesian Institute of Sciences	Nondepartment agency	Basic sciences	1,591
Central Statistics Agency	Nondepartment agency	Statistics	1,842
National Nuclear Energy Agency	Nondepartment agency	Nuclear energy	1,344
National Institute of Aeronautics and Space	Nondepartment agency	Aeronautics and space	480
National Coordination Agency for Survey and Mapping	Nondepartment agency	Mapping	194
Agency for Agricultural Research and Development	Ministry of Agriculture	Crops, livestock, and fisheries	3,008
Indonesian Research Institutes for Estate Crops	Indonesian Planters Association for Research and Development (Ministry of Agriculture coordination)	Estate crops (oil palm, rubber, sugar, tea, coffee, cacao, quinine)	296
Forestry Research and Development Agency	Ministry of Forestry	Forestry	417
Agency for Public Works Research and Development	Ministry of Public Works	Infrastructure	495
Center for Oil and Gas Technology Research and Development	Ministry of Energy and Mineral Resources	Oil and gas	343
Center for Mineral Technology Research and Development	Ministry of Energy and Mineral Resources	Mining	145
Agency for Health Research and Development	Ministry of Health	Health	326
Agency for Education Research and Development	Ministry of National Education	Education	267

Sources: Data refer to the number of research staff with university degrees (B.Sc., M.Sc., or Ph.D.) in 1997 (except for the Ministry of Energy and Mineral Resources data, which are for 1995). Number of scientists at Agency for Agricultural Research and Development from AARD 1997. Number of scientists at Indonesian Research Institutes for Estate Crops from IFPRI 2004. Number of scientists at Ministry of Energy and Mineral Resources from RISTEK 1996, and at all other research institutes from RISTEK 1998.

fragmentation, low agricultural-sector wages, and limited rural employment opportunities. Investments are needed in rural areas to provide employment opportunities. Agricultural development will require increased commercialization of agriculture in the form of agribusiness development and value-adding activities.

- While population growth remains high and rice is still the favored food staple, self-sufficiency is threatened by climatic variability, pest and disease outbreaks, and unstable market forces. Moreover, the land area available for rice has diminished, especially on Java, where land is being converted to industrial development and housing. Rice yields have leveled out. More irrigated land and use of inherently less productive land for rice are needed. At the same time, food production and consumption need to be diversified.

- Land fragmentation will remain a problem until industrialization draws enough small landholders out of agriculture to enable “extensification” of agricultural production. Farming systems research that allows for efficient agricultural production on small landholdings is needed.

- Rural financial institutions have not performed well in providing capital to agriculture. Better incentives are needed for these institutions to mobilize capital for agriculture.

- Future policy must capitalize on the competitive advantage of different agro-ecological zones. This entails a focus not only on cultivation techniques but also on farming systems, integrated pest management, and reduction in post-harvest losses.

- More practical farm-management skills are needed, including decisionmaking tools and bookkeeping methods that normally accompany the transition from subsistence to commercial agriculture.

- Increased environmental awareness is important not only to maintain the resource base but also to allow Indonesia to be competitive in international markets.

Elsewhere in the strategic plan, attention is drawn to water scarcity as a potential impediment to increased agricultural output. One of the challenges will be to develop agricultural technology and plant varieties that are more efficient in water use. Another will be the development of on-farm and multifarm strategies for water management.

Finally, reference must be made to the political situation since the fall of the New Order government in 1998. One outcome of this situation (and, to some extent, the cause) has been a demand for greater democracy and public participation in decisionmaking. Decisions about agricultural R&D activity will need to be increasingly decentralized, in the sense of taking account of farmers' wishes and perceived needs. This shift will entail a greater research emphasis on farming systems and less on commodity production.

Financing and Provision of Agricultural R&D

A Brief History of Agricultural Research in Indonesia

Agricultural research in Indonesia dates back to the establishment of tropical botanical gardens by Dutch colonial authorities in the early 1800s. The purposes of these gardens were to collect and study tropical plant species and introduce new export commodities to the colonies. The most prominent was the botanical garden in Bogor, West Java, established in 1817. During the 19th century, the garden accommodated a large number of specialists and made considerable contributions to fundamental studies in tropical botany, but scientists gave scant attention to the practical problems of farming (Oudejans 1999).

Applied agricultural research was stimulated by plantation owners who demanded solutions to immediate crop management and disease problems. Plantation growers, producing mainly for export, could profit from an expansion of supply and, through their associations, had the means to fund commodity-oriented research. Sugarcane planters were among the first to establish a research station, in East Java in 1887, followed by planters of coffee and cacao in 1901, tea in 1902, tobacco in 1907, and rubber in 1916. Most of these experiment stations remained relatively small, usually with fewer than 10 senior scientists. An exception was the sugar research station, which, by the 1920s, had a staff of 35 Europeans and more than 200 Indonesians (Oudejans 1999). Sugar scientists made significant technical advances, such as discovering a method for sexually crossing sugarcane that allowed breeders to develop disease-resistant varieties. These advances led to dramatic increases in sugar yield in the early years of the 20th century (Pray 1991).

Government-supported agricultural research was given a firmer footing with the establishment of a Department of Agriculture in 1905 under the leadership of Melchior Treub. Treub was a highly regarded Dutch scientist who sought to organize the new department along the lines of the U.S. Department of Agriculture, which at that time placed a heavy emphasis on research. The new department was mainly concerned with plantation crops, although an experiment station for rice and secondary food crops was established near Bogor in 1907. The commitment to food-crop research was insufficient to boost crop yields significantly, and in the 1920s and 1930s rice production lagged behind population growth, forcing Indonesia to import food staples.

Agricultural research in Indonesia was severely disrupted by World War II (1942–45), the War of Independence (1945–49), and a steadily deteriorating economy during the 1950s and early 1960s. Many foreign-owned plantations were nationalized during this period. A subsequent sharp decline in plantation production curtailed support for the plantation-supported experiment stations. The decrease in numbers of scientific and technical personnel engaged in agricultural research was not reversed until the late 1960s.

The New Order government of President Suharto, which came to power in 1965–66, set improved macroeconomic policies and established food self-sufficiency as a national priority. Funding for agricultural research was gradually increased. To improve the coordination of agricultural research, a new Agency for Agricultural Research and Development (AARD) was established within the Ministry of Agriculture in 1974. AARD was given overall responsibility for food, forestry, and fisheries research. In 1979, the Indonesian Planters Association for Research and Development (IPARD), a consortium of state-owned and private estates that supports research on estate crops, was brought under AARD's oversight. In 1983, forestry research was spun off from AARD into the newly established Ministry of Forestry, and in 2001 fisheries research was transferred from AARD to the new Ministry of Marine Affairs and Fisheries. AARD continues to have responsibility for crop and livestock research, agricultural economics research, agricultural resources research, and, through IPARD, estate-crops research.

Overview of the Institutional Structure of Agricultural Research

In Indonesia, the central government is the primary source of funds for agricultural research (Fuglie 1999). The international donor community has played a major role in supporting agricultural research in Indonesia, especially during the 1980s and early 1990s, when Indonesia's capacity in agricultural research was greatly expanded (Pardey, Eveleens, and Abdurachman 2000). Most government expenditures for agricultural research are directed toward commodities important to smallholders. Research institutes for estate and export commodities are largely funded through contributions by large growers. In-house research by private companies in Indonesia is growing but remains limited (Pray and Fuglie 2002).

The principal role of universities in agricultural research has been to train the scientific and technical personnel employed in government research institutes and the private sector. University scientists also engage in research activities when special project funding can be obtained. Funding for university research may come from AARD, the Ministry of Research and Technology, international donors, the private sector, or other sources.

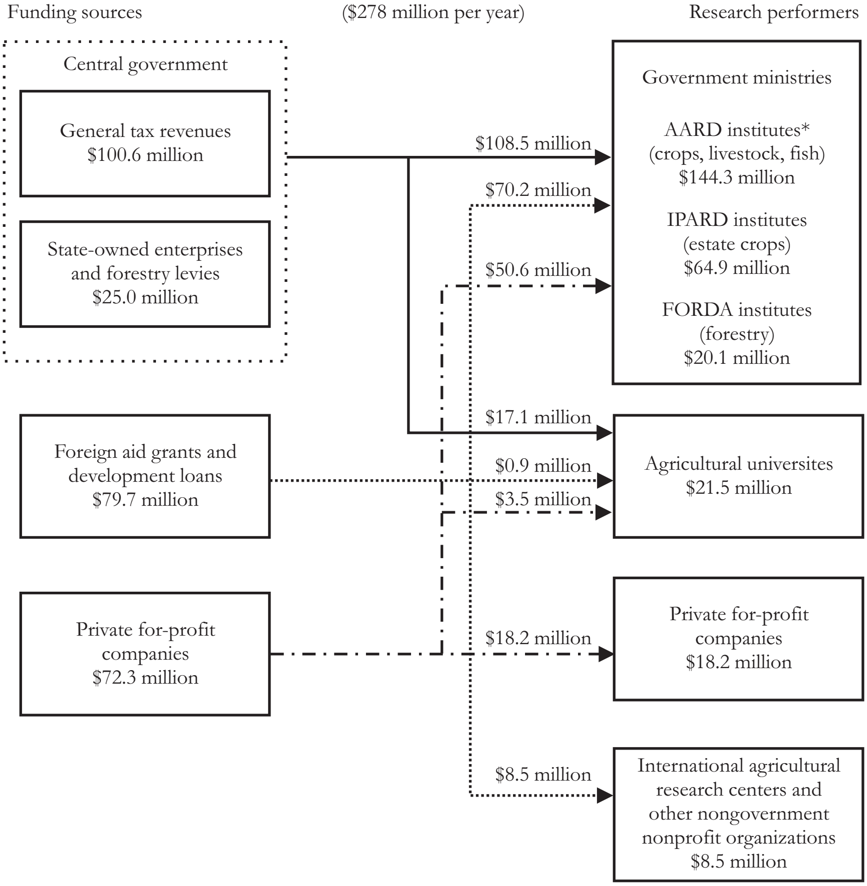
International agricultural research centers play an important role in Indonesia's agricultural research system. Indonesia hosts the headquarters of the Center for International Forestry Research (CIFOR) and the Southeast Asia regional offices of the World Agroforestry Centre (formerly ICRAF) and the International Potato Center (CIP). The United Nations Centre for Alleviation of Poverty through Secondary Crops' Development in Asia and the Pacific (CAPSA), and the ASEAN-funded Southeast Asia Regional Center for Tropical Biology (BIOTROP) are also located in Indonesia. AARD has cooperative research arrangements with several other international agricultural research centers—including the Asian Vegetable Research and Development Center (AVRDC), the International Maize and Wheat Improvement Center (CIMMYT), the International Livestock Research Institute (ILRI), and International Rice Research Institute (IRRI)—and agricultural research institutes in Japan, Europe, North America, and Australia.

In the 1990s, AARD research institutes and agricultural universities began to explore new ways of self-financing at least part of the costs of agricultural research. Although government policy so far does not allow government agencies to retain funds raised through product sales, AARD established a semi-autonomous foundation in 1999, the Intellectual Property and Technology Transfer Management Office (IPTTMO), to help commercialize AARD innovations. This office has responsibility for patenting and licensing AARD innovations to private firms. IPTTMO has the legal authority to retain earnings from technology licensing. Between 1998 and 2001, IPTTMO had obtained 36 patents on AARD inventions (AARD 2003), mostly for machinery innovations, animal vaccines, and feed additives.

Intellectual property rights (IPR) for inventions and creative works are relatively new to Indonesia and remain poorly enforced. A national patent law was enacted in 1991 and amended in 1997 and 2001 to bring it into compliance with the World Trade Organization's agreement on Trade-Related Aspects of Intellectual Property (TRIPs). In 1997, Indonesia signed the international Patent Cooperation Treaty. IPR for agricultural innovations were strengthened by the 1997 amendments to the patent law, which eliminated a provision barring plant and animal patents, and by the passage of plant breeders' rights legislation in 2001.

The principal funders and performers of agricultural research in Indonesia are shown in Figure 4.1. We estimate that total spending for agricultural research in

Figure 4.1 Indonesia: Funding channels for agricultural research, 1998–99



Sources: Government finance and expenditures from AARD 2000; FORDA 1997; R. Sumitro, personal communication 2001. University expenditures based on IPB 2000. Private expenditures from Pray and Fuglie 2002.

Notes: Figures are in 1999 international dollars and are estimates only.

***In 2001, fisheries research moved from AARD to the Ministry of Marine Affairs and Fisheries.**

Indonesia in 1998–99 was about $278 million in 1999 international dollars. The central government provided about $126 million from tax revenues, contributions of state-owned estates for estate-crop research, and forest concession levies. Foreign assistance (especially in the form of loans from the World Bank and the Asian Development Bank) provided another $80 million. Private companies conducted about $18 million of their own research and purchased about $50 million of planting materials and other technology products from estate-crop research institutes. These earnings are used to support research on estate crops. Government institutes were the largest research performers, conducting $229 million worth of research. Research at agricultural universities is estimated to be $21.5 million. International agricultural research centers performed at least $8.5 million worth of research in Indonesia.

Organizational Changes in Public Agricultural Research

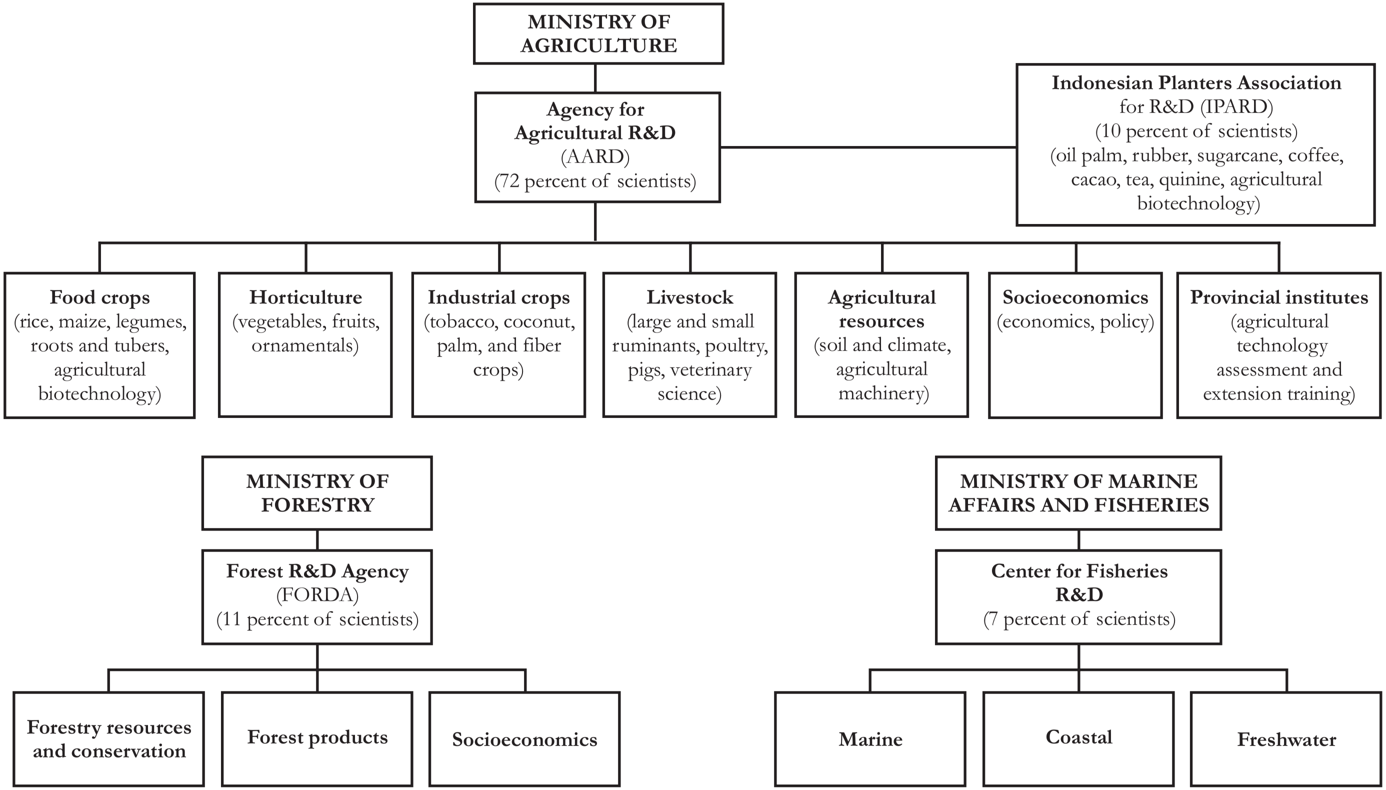
As described above, public agricultural research in Indonesia has undergone several reorganizations since the establishment of AARD in 1974. These reorganizations reflect the growing capacity and widening agenda in agricultural research. Figure 4.2 shows the organization of agricultural research within government ministries as of 2001. More than 70 percent of agricultural scientists were housed in AARD, with the rest distributed among IPARD, FORDA, and the fisheries institutes.

AARD underwent a major internal reorganization in 1995 to decentralize its agricultural research efforts. Some regional substations of the Central Food Crop Research Center (CRIFC) were upgraded and given mandates to lead research on specific commodities. In addition, technology assessment centers were established in each province to link research, extension, and on-farm testing of new technologies. These changes reflected the steadily growing research capacity of the regional substations, increased emphasis on other commodities once rice self-sufficiency was approached in the mid-1980s, and concern that linkages between research and extension were inadequate to move technology into the hands of small farmers quickly. These provincial-level assessment institutes for agricultural technology may eventually be transferred to provincial government control as part of the trend toward decentralization of Indonesian government services.

Research linkages between AARD and both the universities and the private sector have recently been strengthened with the support of loans from the World Bank and the Asian Development Bank (ADB). The ARMP-II (World Bank) and PAATP (ADB) projects set aside special funds for collaborative research projects between AARD scientists and universities, international centers, and private companies. Foreign and private partners are required to provide matching funds. Through these projects, AARD raised 684 million rupiah and IPARD 845 million rupiah in matching contributions from private companies in 2001 (AARD 2001).

Since the 1980s the government of Indonesia has made a concerted effort to expand national capacity in biotechnology research. In 1988, the government designated three institutions as "centers of excellence" for biotechnology research: the University of Indonesia in Jakarta for medical applications, the Agency for the

Figure 4.2 Indonesia: Organization of agricultural research within government ministries, 2001



Source: Compiled by authors.

Assessment and Application of Technology (BPPT) for industrial applications, and AARD for agricultural applications. In 1993, the Center for Research and Development of Biotechnology at the Indonesian Institute of Sciences (LIPI) was assigned as a second center of excellence for agricultural biotechnology (Moeljopawiro 1999). Agricultural biotechnology research within AARD is concentrated at the Center for Agricultural Biotechnology and Genetic Resources in Bogor.[4]

AARD has relied heavily on foreign-funded special projects to develop its agricultural biotechnology research capacity, such as the Rockefeller Foundation's Rice Biotechnology Network, led by IRRI; the USAID-funded project on Agricultural Biotechnology for Sustainable Productivity, led by Michigan State University; and World Bank loan funds (Fagi and Herman 1998). Falconi (1999) reported that in 1997 AARD spent US$6.0 million (18.7 million in international dollars) on agricultural biotechnology research. Falconi estimated that about 85 percent of agricultural biotechnology research was done by government research institutes, 11 percent at universities, and 4 percent in the private sector. Food crops received the greatest share of these resources.

Several applications of biotechnology to agriculture have been under development, including cell and tissue culture for plant propagation, marker-selected breeding, the use of monoclonal antibodies for disease diagnosis, and the development of genetically modified crops (Moeljopawiro 1999). In 1997, the Ministry of Agriculture issued biosafety regulations for field-testing genetically modified organisms. In 2001, several hundred hectares of a *Bacillus thuringiensis* cotton variety developed by Monsanto were grown in Indonesia, the first genetically modified organism approved for commercial use in the country.

Funding and Staffing of Public Agricultural Research

Over the past three decades, Indonesia has significantly boosted its capacity in agricultural research. When AARD was formed in 1974, only seven of its agricultural scientists held Ph.D. degrees. By 2003, the education status of agricultural scientists employed at AARD, IPARD, and fisheries had increased to 355 Ph.D.s, 1,095 M.Sc.'s, and 2,187 with bachelor's degrees, not including research staff for forestry (Table 4.8). Research expenditures also increased in real terms, from around $100 million in 1974 to $270 million in 2003 (constant international dollars), although funding per scientist declined. The sharp increase in the number of AARD scientists between 1994 and 1995, especially at the B.Sc. level, reflects an internal reorganization that amalgamated certain agricultural extension and research functions when provincial assessment institutes for agricultural technology were formed. But, despite this rapid growth, expenditures for agricultural research in Indonesia as a percentage of agricultural GDP and as a percentage of total government expenditure still ranked near the bottom of those for developing countries in Asia (Pardey, Roseboom, and Fan 1998). Furthermore, the economic and political crises of the late 1990s took their toll on agricultural research, with real expenditures falling from $283 million in 1997 to $202 million in 2000. Research expenditures began to recover after 2000 and were nearly back to precrisis levels by 2003.

Setting Priorities for Agricultural Research

The selection of agricultural research projects for the allocation of development funds at AARD institutes involves a series of screening steps that start with the individual scientist and move up the AARD hierarchy to the AARD Secretariat. For example, a proposal on rice breeding would first be cleared by the Rice Research Institute at Sukamandi, West Java, then forwarded to the Central Research Institute for Food Crops in Bogor and finally to the AARD Secretariat in Jakarta. Evaluations at each step are mostly internal, although since 1999 AARD has also used external reviewers from universities and other government science institutes. The principal criterion used by AARD is quality of research.

Proposals approved by the AARD Secretariat are forwarded to the National Planning Agency (BAPPENAS), where they are evaluated for their contribution to economic development goals and their potential economic value. However, formal benefit–cost analysis is generally not used. Valuation is based largely on the importance of the commodity to Indonesia's agriculture. Consideration is given to economic value, food security, poverty, and the geographic focus of the research.

Agricultural research in Indonesia has received substantial financial support through loan projects from the World Bank and Asian Development Bank. These loans typically require the government to provide matching funds from current revenues. The Ministry of Finance has a role in evaluating and approving all government loan projects. In addition, the Ministry of Finance evaluates research project budgets against standard cost guidelines for land, labor, travel, materials, and so on.

Since the national elections in 1999, the Indonesian House of Representatives (DPR) has become active in establishing government policies and budget priorities. Cabinet ministers and directors of government agencies must increasingly provide justification for their budgets and programs to legislators. This trend has added a new dynamic in mobilizing domestic support for agricultural research.

Sources of Funds for Agricultural Research

Financial support for public research in Indonesia comes from a number of sources, including the central government budget, special assessments on commodity groups, foreign assistance, and funds raised by the research stations themselves through product sales, technology licenses, and contract research.

Table 4.8 Indonesia: Agricultural research funding and staffing, 1974–2003

	Agricultural research expenditures			Number of agricultural scientists (SY)				Expenditure per scientist	
Year	Million current rupiahs	Million 1999 rupiahs	Million 1999 international dollars	Ph.D.	M.Sc.	B.Sc.	Total	Million 1999 rupiahs per SY	Constant 1999 international dollars per SY
1974	8,417	197,061	104.13	NA	NA	NA	NA	NA	NA
1975	10,516	221,430	117.01	11	33	294	338	655.118	346,182
1976	16,199	295,508	156.15	25	34	383	442	668.571	353,291
1977	17,954	289,135	152.79	28	39	500	567	509.939	269,465
1978	21,030	309,475	163.54	29	40	513	582	531.745	280,988
1979	23,005	253,383	133.89	35	51	632	718	352.902	186,483
1980	36,269	304,962	161.15	46	143	704	893	341.502	180,459
1981	43,545	331,530	175.19	48	151	714	913	363.121	191,883
1982	48,188	345,917	182.79	55	172	843	1,070	323.287	170,833
1983	66,766	419,493	221.67	68	249	934	1,251	335.326	177,195
1984	75,539	439,259	232.12	92	271	1,040	1,403	313.085	165,443
1985	77,656	433,014	228.82	115	311	1,074	1,500	288.676	152,544
1986	91,397	510,129	269.57	143	342	1,486	1,971	258.817	136,766
1987	99,471	480,945	254.14	157	432	1,254	1,843	260.958	137,897
1988	96,020	411,777	217.59	176	475	1,420	2,071	198.878	105,092
1989	88,861	346,455	183.08	193	505	1,633	2,330	148.693	78,573
1990	109,927	397,859	210.24	242	645	1,543	2,430	163.728	86,518
1991	121,079	402,675	212.78	241	651	1,549	2,441	164.963	87,171
1992	141,415	446,361	235.87	251	678	1,677	2,606	171.282	90,510
1993	138,971	402,872	212.89	271	719	1,727	2,717	148.278	78,354
1994	172,061	462,809	244.56	281	761	1,741	2,783	166.299	87,877
1995	188,632	462,503	244.40	305	823	2,184	3,312	139.645	73,792

1996	217,261	489,371	258.60	320	821	2,163	3,304	148.115	78,268
1997	268,238	536,722	283.62	320	820	2,164	3,304	162.446	85,841
1998	393,385	449,092	237.31	332	816	2,246	3,393	132.359	69,942
1999	387,072	387,072	204.54	341	813	2,327	3,481	111.196	58,759
2000	418,922	382,134	201.93	346	849	2,489	3,684	103.728	54,813
2001	484,865	399,253	210.98	348	908	2,426	3,682	108.434	57,299
2002	539,394	414,466	219.01	347	953	2,321	3,620	114.493	60,501
2003	708,028	510,639	269.84	355	1,095	2,187	3,637	140.401	74,192

Sources: Research expenditures for AARD institutes: 1974–83 from Pardey, Eveleens, and Abdurachman 2000 (Table Appendix 2); 1984–85 from AARD 1991; 1986–92 from AARD 1992b; 1993 from AARD 1994; 1994–95 from AARD 1997; 1996–98 from AARD 1999b; 1999–2003 from AARD 2003. Research expenditures for IPARD institutes: 1974–83 from Pardey, Eveleens, and Abdurachman 2000 (Table Appendix 2); 1984–85 government contribution from Pardey, Eveleens, and Abdurachman 2000, and member contribution from AARD 1990; 1986–88 from AARD 1992b; 1989–93 from R. Sumitro, personal communication 2001; 1994–2003 from IFPRI 2004. A major source of funds for IPARD institutes is derived from product sales (around 75 percent in 1998), but these data are only available from 1989 onward. Revenue from product sales was estimated for 1974–88 using a constant revenue-per-scientist ratio (1989–2000 average in constant 1999 rupiah). Research staff for AARD institutes: 1975–86 from Pardey, Eveleens, and Abdurachman 2000 (Table Appendix 6); 1987 from AARD 1987b; 1988 from AARD 1988; 1989 from AARD 1989; 1990 from AARD 1990; 1991 from AARD 1991; 1992 from AARD 1992b; 1993 from AARD 1993; 1994 from AARD 1994; 1995 from AARD 1995; 1996 from AARD 1996; 1997 from AARD 1997. Data for 1998 are an estimated average of data for 1997 and 1999; 1999 is from AARD 1999b; 2000 from AARD 2000; 2001 from AARD 2001; 2002 from AARD 2002; 2003 from AARD 2003. Research staff for IPARD institutes: 1975–93 from Evenson et al. 1994 (Table A1.5); 1994–2003 from IFPRI 2004.

Notes: Research expenditures and staff are for AARD and IPARD (estate crops) institutes. AARD included forestry research until 1982. During 1999 and 2000, industrial crop-research institutes were temporarily transferred to the Ministry of Forestry, and their expenditures and staff were not reported in AARD publications (they were transferred back to AARD in 2001). After 2000, fisheries research was transferred from AARD to the newly formed Ministry of Fisheries and Marine Resources. To keep coverage consistent, the numbers in this table have been adjusted to include the industrial crop institutes during 1999 and 2000 and fisheries research for the years 2001 through 2003. The 1974–99 fiscal years are from April to March; 2000 fiscal year is from April–December only. 2001–3 fiscal years are from January to December. SY indicates science years. Rupiahs were converted to international dollar denominated currency units using purchasing power parity from World Bank 2005; the GDP price deflator is from International Monetary Fund 2001. NA indicates that data are not available.

In times of financial austerity, the government's development budgets may be sharply reduced, while routine budgets remain largely unaffected. Development budgets for agricultural research have been relatively unstable: between 1986–90 and 1998–2000 the agricultural research development budget was cut by more than 60 percent in real terms from the years immediately preceding (Table 4.9). Foreign loans and grants played a major role in stabilizing research funds during these periods. In the late 1980s, the U.S. government provided significant grant assistance for AARD. In the late 1990s and early 2000s, the World Bank and the Asian Development Bank provided large loans for agricultural research. The loan programs have been particularly crucial for supporting the strengthening of the provincial assessment institutes for agricultural technology.

The main sources of funds for agricultural research differ significantly among commodities. Government revenues supplemented with foreign loans and grants make up the bulk of AARD's budget for crops and livestock. For forestry research, government revenues provide about one-third of the annual budget; most of the remainder comes from the forestry sector through a special assessment on forest concessions.

Research on estate crops is mainly financed by the plantation sector itself. IPARD's semi-autonomous status allows estate-crop research institutes to keep revenues from product sales. Further, members of IPARD contribute funds for research on estate crops.[5] These two sources fund about 95 percent of plantation research in Indonesia. Government contributions account for only about 5 percent. In part because of the different mechanisms for financing agricultural research and the special status of IPARD,[6] scientists working at the plantation-crop research institutes are significantly better funded than researchers at AARD. In 1996, research expenditures per scientist at IPARD institutes were about four times higher than at AARD institutes.

Research at universities is funded mainly from government sources, including competitive grant programs. In 1998–99, Bogor Agricultural University (IPB) raised over 10 billion rupiah to support research projects. About 80 percent of this was from government research funds, 16 percent from the private sector, and the remainder from foreign sources (IPB 2000).[7]

A small but growing share of agricultural research in Indonesia is conducted by private companies (Table 4.10). Such research is estimated to have increased from $6.6 million to $18.2 million between 1985 and 1996 (in constant 1999 international dollars). Privately owned rubber and oil palm plantations conduct some in-house research outside the IPARD system; they spent about $6 million for research in 1996. Private seed companies began breeding activities in Indonesia in the late

Table 4.9 Indonesia: Sources of funding for agricultural research at AARD and IPARD, 1974–2003 (million 1999 international dollars)

	Government of Indonesia				
Year	Routine	Development	Estates	Foreign	Total
1974	11.0	47.5	25.3	20.4	104.2
1975	15.2	54.6	27.5	19.7	117.0
1976	15.8	78.4	27.8	34.2	156.2
1977	18.6	62.0	27.4	44.7	152.7
1978	21.3	73.7	28.7	39.8	163.5
1979	17.2	57.1	26.3	33.3	133.9
1980	20.0	66.1	30.5	44.5	161.1
1981	24.1	67.5	33.9	49.8	175.3
1982	24.1	72.5	34.8	51.3	182.7
1983	23.7	57.9	38.9	101.2	221.7
1984	23.3	58.5	44.3	106.0	232.1
1985	27.9	66.2	62.0	72.7	228.8
1986	33.8	33.0	72.3	130.5	269.6
1987	29.0	5.4	62.1	157.7	254.2
1988	29.0	8.1	60.3	120.2	217.6
1989	29.1	15.0	68.4	70.7	183.2
1990	31.7	17.8	89.9	70.9	210.3
1991	34.8	45.4	80.6	52.0	212.8
1992	40.2	52.8	83.1	59.8	235.9
1993	42.5	58.8	76.6	35.0	212.9
1994	57.3	70.4	74.2	42.6	244.6
1995	65.3	76.5	84.2	18.4	244.5
1996	68.2	77.7	73.9	38.8	258.6
1997	71.0	77.4	89.8	45.4	283.6
1998	41.1	27.2	67.9	101.0	237.2
1999	47.6	36.1	50.6	70.2	204.5
2000	46.1	21.4	47.9	86.5	201.9
2001	56.1	34.6	42.5	77.7	210.9
2002	57.5	46.9	47.7	67.0	219.0
2003	62.4	64.5	54.0	89.0	269.9

Sources: Sources of funds for AARD institutes: 1974–83 from Pardey, Eveleens, and Abdurachman 2000 (Table Appendix 2); 1984–85 from AARD 1991; 1986–92 from AARD 1992b; 1993 from AARD 1994; 1994–95 from AARD 1997; 1996–98 from AARD 1999b; 1999–2003 from AARD 2003. AARD funding amounts have been adjusted to include industrial crop institutes during 1998–99 and fisheries institutes during 2001–3, years for which funding for these institutes is not recorded in AARD publications. Sources of funds for IPARD institutes: 1974–83 from Pardey, Eveleens, and Abdurachman 2000 (Table Appendix 2); 1984–85 government contribution from Pardey, Eveleens, and Abdurachman 2000 and member contribution from AARD 1990; 1986–88 from AARD 1992b; 1989–93 from R. Sumitro, personal communication 2001; 1994–2003 from IFPRI 2004. A major source of funds for IPARD institutes is product sales (around 75 percent in 1998), but these data are only available from 1989 onward. Revenue from product sales was estimated for 1974–88 using a constant revenue-per-scientist ratio (1989–2000 average in constant 1999 rupiahs).

Note: Rupiahs were converted to international dollar denominations using purchasing power parity (PPP) indexes from World Bank 2005; the GDP price deflator is from International Monetary Fund 2001.

Table 4.10 Indonesia: Private agricultural research, 1985 and 1996

Research focus	Expenditure (million 1999 international dollars) 1985	Expenditure (million 1999 international dollars) 1996	Number of companies doing research 1985	Number of companies doing research 1996
Crop breeding	0.0	2.1	0	6
Crop protection	2.6	7.2	1	6
Plantations	2.0	6.0	3	4
Animals	2.0	3.0	3	3
All	6.6	18.2	7	19
Percentage of all agricultural research	3.125	7.003		
Percentage of agricultural GDP	0.010	0.018		

Source: Pray and Fuglie 2002.

Note: Rupiahs were converted to international dollar denominations using purchasing power parity (PPP) indexes from World Bank 2005.

1980s, mainly in hybrid corn and vegetables, but annual research expenditures were only $2.1 million by the mid-1990s. Chemical companies conduct crop-protection research for screening and registering new pesticides. At least one multinational chemical company operated a research station in Indonesia for screening new chemical compounds under tropical conditions. Research on animal production was conducted mainly by large integrated poultry producers. As a share of total agricultural research conducted in Indonesia, private research increased from 3.1 percent to 7.0 percent between 1985 and 1996. Thus, private research, while still relatively small-scale, grew more rapidly than public research. Private research also grew relative to the size of the Indonesian agricultural sector.

Allocation of Agricultural Research Funds

Detailed information on the allocation of scientific resources for agriculture in Indonesia is presented in Table 4.11. Commodity institutes generally have about twice as many M.Sc.s as Ph.D. holders. However, the institutes that focus on biotechnology (one for food crops and one for estate crops) employ more Ph.D.s The provincial assessment institutes for agricultural technology (AIATs) have a relatively large number of staff with only bachelor's degrees, many of whom work in extension training. Most of the growth in AARD research staff since 1995 has occurred in the AIATs.

We used the allocation of scientists among commodity-oriented institutes to develop some parity ratios for research resource allocation in Indonesia. We define the parity ratio as the number of scientist years (SY) per billion international dollars of value-added production for a commodity group. Parity ratios provide a rough first approximation for assessing the allocation of research resources among

Table 4.11 Indonesia: Number of agricultural researchers by institution, 1997

	Number of scientists per institution			
Institution	**Ph.D.**	**M.Sc.**	**B.Sc.**	**Total**
AARD centers and institutes				
Food Crops Research Center	8	13	22	43
Biotechnology	34	22	71	127
Rice	14	24	55	93
Legumes and root crops	7	37	47	91
Corn and cereals	9	32	62	103
Swamp crops	6	24	44	74
Total food crops research	78	152	305	535
Horticultural Research Center	3	4	14	21
Vegetables	9	16	37	62
Fruits	4	9	43	56
Ornamentals	8	18	34	60
Total horticultural research	24	47	125	196
Animal Research Center	1	3	9	13
Animal production	40	40	56	136
Veterinary science	10	26	28	64
Total animal research	51	69	93	213
Fisheries Research Center	4	5	13	22
Saltwater fish	14	27	55	96
Freshwater fish	5	27	57	89
Coastal water fish	3	20	60	83
Total fisheries research	26	79	185	290
Industrial Crops Research Center	5	10	28	43
Medicinal plants	13	32	77	122
Tobacco and fiber crops	6	20	62	88
Coconut and palms	2	17	26	45
Total industrial crops research	26	82	208	316
Agricultural machinery	1	7	36	44
Soil and climate	14	50	95	159
Agricultural socioeconomics	20	45	57	122
Assessment Institutes for Agricultural Technology (AIAT)	27	167	793	987
AARD Secretariat and planning	9	29	66	104
AARD library and information	0	11	31	42
Total AARD institutes	276	738	1,994	3,008
IPARD institutes (plantation crops)				
Oil palm	11	31	46	88
Rubber	17	41	57	115
Sugar	16	29	67	112
Coffee and cacao	8	17	17	42
Tea and quinine	4	15	21	40
Biotechnology and agribusiness	10	8	14	32
Total estate crops (IPARD)	66	141	222	429
Forestry institutes (FORDA)	30	117	339	486
Total agriculture	372	996	2,555	3,923

Sources: Scientists at AARD institutes from AARD 1997. IPARD scientists from R. Sumitro, personal communication 2001. Forestry scientists from FORDA 1997.

Note: Fisheries research was transferred from AARD to the Ministry of Marine Affairs and Fisheries in 2001.

Table 4.12 Indonesia: Parity ratios for agricultural research by commodity group, 1997

Commodity group	Value-added (billion dollars per year)	Number of scientists (SY) in 1997 Ph.D.	M.Sc.	B.Sc.	Total SY	Parity ratio (SY per billion dollars)
Nonfood crops	17.5	88	221	396	705	40.4
Forestry	12.8	30	117	339	486	38.0
Fisheries	13.7	26	79	185	290	21.2
Livestock	13.7	51	69	93	213	15.6
Food crops	38.1	78	152	305	535	14.0
Horticulture	18.8	24	47	125	196	10.4
Total	126.0	297	685	1,443	2,425	19.2

Sources: Value-added for commodity crops is from Warr and Azis 1997. Scientists at AARD and IPARD institutes from AARD 1997.

Notes: Value-added is averaged over 1989–93 in 1999 international dollars. SY indicates scientist years.

commodities. It should be kept in mind that equal parity among commodities may not be economically or socially optimal (Ruttan 1982).

For all agriculture research, there was an average of 19 SY per billion dollars in value-added in the agricultural sector. The parity ratio for research on nonfood crops (estate and industrial crops) was double the average, at 40 SY per billion dollars in value added. Research on food crops, livestock, and horticulture received the least attention, with only 10–15 SY per billion dollars in value added. Also, funding per scientist at IPARD institutes (estate crops) is substantially higher than funding per scientist at AARD institutes, further widening the gap in parity among commodity groups. The disparity in parity ratios between research on estate crops versus other crop and livestock commodities reflects both the longer history of estate-crop research in Indonesia and the ability of these institutes to finance research through commodity sales and producer contributions.

Accountability and Impact of Agricultural Research

The investment in agricultural R&D has brought significant benefits to the Indonesian economy. One indicator of its effectiveness is the release and dissemination of new crop varieties. Between 1969 and 2003, at least 668 new crop varieties were released in Indonesia (Table 4.13). About one-quarter of the new releases were high-yielding rice varieties. Improved rice varieties had been disseminated to nearly two-thirds of rice-growing areas by 1991 (mostly to wetland rice areas). New varieties of soybean and maize were also widely disseminated in the 1980s. Another indicator of the benefits from research is the increased rate of growth in total factor productivity in crop and livestock agriculture during the 1970s and 1980s (Fuglie 2004).

Measurement of the economic value of research outcomes has so far not entered into the formal evaluation of agricultural research in Indonesia. Only a few studies have been carried out on the economic impact of agricultural research. Salmon (1991) estimated that rice research expenditures between 1965 and 1977 achieved an annual internal rate of return of 151 percent. Evenson et al. (1997) estimated rates of return to research for eight food crops (1968–92), six vegetable crops (1982–92), and six fruit crops (1982–92). They found a significant correlation between the level of research investments and the rate of productivity growth for most of these commodities. Estimated rates of return to research exceed 100 percent for wetland rice, dryland rice, maize, soybeans, sweet potatoes, all six vegetable crops, and three out of the six fruit crops included in the study. Only research on cassava and mangoes showed no impact. The high rates of return to research reflected the very low level of research investment relative to commodity value. Thus, any positive statistical association found between research and productivity would necessarily result in a high marginal rate of return to research (Evenson et al. 1997).

One limitation of the returns-to-research studies is that they probably did not fully account for the contributions of research conducted outside the country. Indonesian agriculture has been able to benefit significantly from technologies developed elsewhere and introduced through public and private channels. Indonesia's growing capacity to conduct agricultural research has undoubtedly enhanced its ability to acquire and disseminate new technologies developed elsewhere. But in some cases introduced technologies required little government-supported research. Several of the first releases of new rice varieties, for example, were varieties developed by IRRI in the Philippines. In 1991, one major IRRI variety (IR36) occupied about one-third of the wetland rice growing area in Indonesia (AARD 1992a). Pray and Fuglie (2002) identified several areas where the private sector played a major role in transferring technologies to Indonesia, including new clones of oil palm and rubber from Malaysia, hybrid vegetable and hybrid maize varieties, and hybrid poultry and integrated poultry production systems. The private sector also played a major role in the rapid expansion of coastal shrimp farming in the early 1990s, based on technology developed in Taiwan (World Bank et al. 2002).

The return-to-research studies have been influential in strengthening financial support for agricultural research within the Indonesian bureaucracy and the foreign-aid community. In the late 1990s, the Asian Development Bank and the World Bank financed several loans to expand and strengthen Indonesian agricultural research.

Table 4.13 Indonesia: Number of crop varieties released, 1969–2003

Crop	1969–73	1974–78	1979–83	1984–88	1989–93	1994–98	1999–2003	Total	Area under improved varieties in 1991 (percent)
Food crops									
Rice	4	18	26	27	21	11	42	149	65
Maize	1	1	7	6	11	13	13	52	44
Soybeans	—	1	4	5	15	7	14	46	66
Groundnuts	—	—	5	1	9	3	5	23	
Mungbeans	—	—	5	3	3	4	2	17	
Sweet potatoes	—	2	—	2	3	3	6	16	
Cassava	—	2	—	1	3	4	2	12	
Sorghum	3	—	1	3	2	—	2	11	
Other legumes	—	—	—	1	4	5	—	10	
Wheat	—	—	—	—	2	—	—	2	
Total food crops	8	24	48	49	73	50	86	338	
Horticulture									
Potatoes	—	—	2	1	1	—	9	13	
Vegetables	—	—	—	16	—	8	28	52	
Fruits	—	—	—	22	19	37	39	117	
Ornamentals	—	—	—	—	—	—	45	45	
Total horticulture	0	0	2	39	20	45	121	227	

Nonfood crops								
Sugarcane	—	—	—	2	31	—	NA	33
Rubber	—	—	—	—	1	11	NA	12
Coffee	—	—	—	—	2	3	1	6
Tea	—	—	—	5	—	—	NA	5
Cacao	—	—	—	—	—	4	NA	4
Oil palm	—	—	—	—	1	—	NA	1
Coconut	1	4	—	3	—	—	8	
Tobacco	—	1	—	1	—	—	2	4
Fiber crops	—	—	—	3	7	2	5	17
Spice and nut crops	—	—	—	4	7	—	2	13
Total nonfood crops	0	2	4	15	52	20	10	103
Total number of varieties released	8	26	54	103	145	115	217	668

Sources: Varieties released between 1969 and 1995 reported in AARD 1995; data for 1996 through 1999 from AARD 1999b; data for 2000 through 2003 from AARD 2003. Estimates of area under improved varieties from AARD 1992a for rice and soybean and CIMMYT 1994 for maize.

Note: A dash indicates no varieties released in this period. NA means data not available.

The evidence on previous rates of return to research were cited in the loan proposals and helped convince bank officials that agricultural research was likely to be a high-payoff investment for Indonesia.

Concluding Observations

Indonesia represents a case where agricultural R&D expanded rapidly from almost nil in the last 30 years of the 20th century, but where R&D investment still remains low relative to the size of the country's agriculture. The initial focus on increasing the production of rice in order to enhance national food security was highly successful, but this effort apparently stalled by the 1990s. A major goal of the current R&D effort is to diversify growth to other commodities and farming systems. To that end, the agricultural R&D system has greatly increased the number of commodities, problem areas, and geographical locations in which it conducts research. However, the expansion of the scope of the system in the face of chronic underfunding has resulted in fragmentation and lack of continuity in many agricultural research endeavors.

The Indonesian agricultural research system actually has several distinct components, each with different modes of financing and operations. The largest component of the system is AARD, which is financed primarily from general government revenues and foreign aid. Foreign assistance has been critical in counterbalancing the instability in the government development budget for agricultural research. AARD is attempting to diversify its sources of financing to include revenue from technology licensing and other product sales. But, given weak enforcement of intellectual property rights and restrictive government regulations on the use of revenues earned by public institutions, technology sales are unlikely to become a significant source of funds for AARD in the near term.

A second component of the system is IPARD, which has responsibility for estate crops. Although IPARD is nominally under AARD's wing, it functions largely autonomously and is almost entirely self-financed. IPARD has been more successful than AARD in mobilizing financial support for research, and research intensity for estate crops is considerably higher than for food crops and livestock. An important issue facing IPARD is how it addresses the needs of small producers of estate crops. The productivity of smallholders is far below that of the large estates (AARD 1992a). IPARD's willingness and ability to develop effective delivery systems for small farms will have a major impact on productivity growth in estate-crop production in Indonesia.

Forestry and fisheries research, once part of AARD, now constitute separate components of the system, falling under the jurisdiction of separate ministries.

Forestry research receives about two-thirds of its funding from the forestry sector itself and appears to be relatively well funded. Since fisheries research was separated from AARD in 2001, it has remained relatively small and reliant on government revenue for most of its funding. It is too early to judge how its new status will affect its financing, policies, and impact.

The other components of the agricultural R&D system in Indonesia include the agricultural universities, the private sector, and the international agricultural research centers. Universities have significant intellectual capacity for research but rely primarily on winning competitive grants and other projects from the Ministry for Research and Technology and other government sources. Private-sector research is still relatively small-scale and focused on a few commodities such as estate crops, hybrid crops, poultry, and pesticide utilization. AARD has had relatively good linkages with international agricultural research centers, especially IRRI's rice breeding program. In the 1980s two international centers with mandates for natural resources research (CIFOR and ICRAF) established a significant presence in Indonesia. Linkages among AARD, universities, and private companies were strengthened through special funds established as part of loans projects from the World Bank and ADB. But it is too early to evaluate the effectiveness (and sustainability) of these initiatives.

The Indonesian government has made a concerted effort to build capacity in agricultural biotechnology research. Its strategy has been to concentrate this capacity in a limited number of research institutes. At the same time, its biotechnology resources have been allocated across a large number of commodities and technologies. It has also established a regulatory system for field testing and approving genetically modified organisms for commercial use. By 2001 a few hundred hectares of genetically modified cotton developed by the private sector were grown commercially in Sulawesi.

Like much of the Indonesian central government, the agricultural research system faces a major challenge in adjusting to the new political climate brought about by the political and economic crises that have engulfed the country since 1997 and led to the change of government in 1998. One consequence of the crises was that public investment in agriculture, including agricultural research, fell significantly in real terms. To maintain and enhance its viability and impact, the agricultural research system will need to increase its base of support in the national parliament and among civil society at large. AARD responded early to the need for greater decentralization of government services by establishing agricultural research and extension training centers in each province. Most of the growth in AARD staff since 1995 has been in the provincial centers. A major question facing these centers is whether provincial governments will be willing and able to assume a larger role in supporting them financially. The agricultural research system will need to find new and creative means to increase its financial base and stability.

Notes

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1. This chapter follows the crop classifications of the Indonesian Ministry of Agriculture. Oil palm, rubber, sugarcane, coffee, tea, and cacao are classified as estate crops, even though smallholders play a major role in the production of these crops (and are in fact the major producers of rubber, coffee, and cacao). Other nonfood crops are classified as industrial crops: these include coconut, other palms, tobacco, spices, and fiber crops.

2. For longer-run assessments of productivity changes in Indonesian agriculture, see Booth 1988 and van der Eng 1996. Geertz 1963 provides the classic treatment of changes in indigenous agricultural production in Indonesia (especially Java) from precolonial times to the 1950s.

3. The government of Indonesia classifies its expenditures into “routine” expenditures, for salaries and capital maintenance, and “development” expenditures, for everything else.

4. AARD’s first laboratory for agricultural biotechnology was established in 1989 with financial support from Japan. In 1995, AARD created the Research Institute for Food Crop Biotechnology (RIFCB) to house its growing biotechnology research capacity. In 2001, AARD’s crop and livestock biotechnology research was amalgamated into the newly formed Center for Agricultural Biotechnology and Genetic Resources.

5. Estate-crop research was funded by a cess (tax) on commodity exports until the early 1980s. Now contributions are apportioned among IPARD members in proportion to their total sales. IPARD is composed of 14 state-owned plantation enterprises and 4 to 5 large private plantations (R. Sumitro, personal communication 2001). IPARD has research stations for oil palm, rubber, sugarcane, coffee, tea, and cacao.

6. For example, the salaries of scientists working at the plantation crop institutes, which are not subject to civil service rules, are substantially higher than those of civil servants of similar grade.

7. Agricultural research by Indonesian universities has not been systematically assessed or studied. For this study, we examined the profile of research expenditures for Bogor Agricultural University (IPB) for 1998–99 and simply multiplied these figures by three to obtain an estimate for agricultural research by all universities in Indonesia. IPB has by far the largest agricultural research program of universities in Indonesia. The financing of education and research activities at several national universities (including IPB) is now being significantly changed as these universities acquire autonomous status. One implication is that routine government support will decline and universities will have greater flexibility (and a greater need) to be financially self-sufficient.

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Chapter 5

Korea: Growth, Consolidation, and Prospects for Realignment

Jung-Sup Choi, Daniel A. Sumner, and Hyunok Lee

Introduction

The Great King Sejong initiated an active agricultural research and development (R&D) policy in Korea about 570 years ago. Famous for many scholarly and scientific achievements, including the creation of the Korean phonetic alphabet, he founded a national scholarly institute, known as the "Hall of Worthies," encouraging the most talented scholars in the country to conduct a variety of research activities (Eckert et al. 1990). Sejong's focus was on efforts to improve the welfare of the common people, including the promotion of agriculture to secure an adequate food supply. One part of his agricultural R&D effort was to transfer relatively advanced agricultural techniques used in the southern provinces to the north, where farmers were still using Chinese techniques that were not well suited to Korean conditions. King Sejong sent out officials from Seoul to study advanced agricultural technology and prepared a manual, "Straight Talk on Farming," designed to help advisers and farmers suit their agricultural practices to the agronomic and climatic conditions on the peninsula. Based on survey data, the king reported that the average farming household in the province around Seoul could produce "several times" more using better farming methods. Recognizing the importance of climate to farmers, the crown prince invented a rain gauge, which ranks among the major technological achievements of the period. Every village in the country was required to report rainfall and the amount of rain absorbed into the soil (Eckert et al. 1990). Despite this impressive start, for many reasons, Korean agricultural R&D, Korean agricultural progress, and the Korean economy all languished for much of the next 500 years.

While the ancient history of Korean agricultural R&D is a fascinating and understudied topic, this chapter reviews agricultural R&D policy in South Korea over recent decades. Our working definition of agricultural research and development is conditioned by the available data. It includes efforts to improve farm and related technology and practices by systematic investigation and dissemination of information and products that embody new knowledge. These efforts include all branches of the social, physical, and biological sciences and engineering. We devote most of our attention to research but include information on the formal agricultural extension system as well. We focus on agriculture, including both crop and livestock commodities, but much of the available data include forestry and fisheries in the totals for R&D funding and expenditures. We discuss further limitations on available information below. Before characterizing the R&D system, we attempt to place this information in context by discussing South Korean agriculture and agricultural policy.

Unfortunately, we have been unable to include information about agricultural R&D in North Korea. North Korea does conduct some agricultural research, but no reliable public data are available to describe the system or the extent of the efforts. We know of no systematic study of North Korean agricultural R&D. (Analyses of aspects of the North Korean economy and agriculture include Kim, Lee, and Sumner 1998 and Noland, Robinson, and Scatasta 1997).Therefore we concentrate on South Korea, and in what follows we use the terms *Korea* and *South Korea* interchangeably.

Overview of South Korean Agriculture in Recent Decades

South Korea's rapid economic transformation over the past several decades has been called an economic miracle (Lucas 1993). Per capita income grew from less than US$300 in 1971 to almost US$10,000 in 2000 (in 2000 dollars). In recognition of this transformation, South Korea became a member of the OECD in 2000. By many measures, South Korea is no longer a less-developed country. However, economic growth in Korea has been mostly associated with expansion of the industrial and service sectors. Agriculture has also modernized, but the vulnerable conditions in agriculture, including lagging per capita incomes, have caused Korea to continue to claim developing-country status before the WTO in negotiations on agriculture. Nonetheless, the rapid growth in the rest of the economy has shaped South Korean agricultural policy and changes in agricultural production.

Table 5.1 Korea: Patterns in agriculture, 1970–2000

Year	1970	1975	1980	1985	1990	1995	2000
Farm population (thousand)	14,422	13,244	10,827	8,521	6,661	4,851	4,032
Farm share of population (percent)	44.7	37.5	28.4	20.9	15.5	10.8	8.5
Land per farm household (hectares)	0.9	0.9	1.0	1.1	1.2	1.3	1.4
Total cultivated area (thousand hectares)	3,264	3,144	2,765	2,592	2,409	2,197	2,098
Percentage of cultivated area							
Rice	36.9	38.7	44.6	47.7	51.6	48.1	51.1
Barley	22.4	22.6	12.0	9.2	6.6	4.0	3.2
Soybeans	9.0	8.7	6.8	6.0	6.3	4.8	4.1
Wheat	3.0	1.4	1.0	0.1	0.0	0.1	0.0
Corn	1.4	1.0	1.3	1.0	1.1	0.8	0.8
Vegetables	7.9	8.0	13.6	14.1	13.2	18.3	18.4
Fruits	1.8	2.4	3.6	4.2	5.5	7.9	8.2
Meat production (thousand metric tons)	165	225	424	590	775	1,059	1,189
Percentage of meat production							
Beef	22.4	31.1	21.9	20.0	12.3	14.6	18.0
Pork	50.3	44.0	56.4	58.6	65.5	60.3	60.1
Poultry	27.3	24.9	21.7	21.4	22.2	25.0	22.0
Imports as percentage of total consumption							
Rice	6.9	5.4	4.9	0.0	0.0	1.0	2.0
Barley	0.0	8.0	42.4	36.3	2.6	33.0	53.1
Soybeans	13.9	14.2	64.9	77.5	79.9	90.1	93.6
Wheat	84.6	94.3	95.2	99.6	99.95	99.7	99.9
Corn	81.1	91.7	94.1	95.9	98.1	98.9	99.1
Beef	0.0	0.0	6.9	3.9	47.5	48.6	47.2
Pork and poultry	0.0	0.0	1.8	0.9	0.5	5.6	11.9

Source: MAF, various years.

Production Changes and Commodity Distribution

To provide an overview of South Korean agriculture, Table 5.1 presents summary statistics for the past three decades at five-year intervals. These data provide a context for the discussion of agricultural R&D and allow us to better understand the degree to which agriculture has been transformed.

As recently as 1970, almost 45 percent of the population lived on farms (the U.S. farm population, by comparison, was then less than 4 percent of the population). Three decades later, only 8.5 percent of the population lives on farms. The farm population fell from about 14.4 million to about 4 million as the national population rose from about 32 million to almost 50 million. For the same period, agricultural gross national product (GNP) as a percentage of total GNP declined from 27 percent to about 5 percent. The lower share of GNP indicates persistent income differences between farm and urban households and also some degree of part-time farming.

The average farm area grew during these three decades, but relatively slowly (increasing only 50 percent over a period in which income doubled every six years), and remains small, at less than 1.5 hectares per farm household. Most agricultural land in South Korea is cultivated. Pasture is relatively unimportant. The cultivated area has declined dramatically with urbanization and a rapid reduction in grain production. Since 1970, the share of land used for barley, soybeans, wheat, and corn has declined from about 36 percent to about 8 percent. These declines are all the more dramatic when we consider that the total cultivated areas declined by one-third. The area under fruit and vegetable production grew from less than 10 percent of the total cultivated area to almost 27 percent.

Rice has long been the staple of the Korean diet, and annual per capita consumption is more than 100 kilograms per person. Rice is also the mainstay of South Korean agriculture, as it has been for centuries. Indeed, the rice share of cultivated area actually grew from about 37 percent in 1970 to about 50 percent by 1985 and has remained stable since then. Rice also generates about 50 percent of total crop revenue and about 30 percent of total agricultural GDP, and it is cultivated on about 80 percent of crop farms (MAF, various years).

Along with rapid growth in per capita incomes has come rapid development of the South Korean livestock industry. Table 5.1 shows a sevenfold increase in meat production over three decades, with a gradual increase in the share of pork in the mix of meat production.

Commodity Policy and Trade

Agricultural policies in Korea have been directed toward two main objectives: self-sufficiency in rice and higher rural incomes. The dominance of rice in Korean agriculture was maintained mainly through high import barriers that allowed domestic prices to exceed border prices by a factor of four or five. Relatively tight import controls and high tariffs also applied to many other commodities, such as beef, citrus, and other horticultural crops. The most important goal of domestic agricultural policy was farm income support, and the main instruments were commodity procurement programs, input subsidies, and (to a lesser extent) loan subsidies.

Rice issues have dominated not only trade policy in agriculture but also domestic agricultural policy. Rice continues to account for more than 90 percent of the total aggregate measure of support for South Korean agriculture as calculated for implementation of the Uruguay Round Agriculture Agreement (URAA) (USDA 1999). The major instrument of the internal rice support program has been government procurement of a portion of national rice production. Each year the congress sets a government purchase price and a procurement target. Historically, the government price has been about 20 percent above the market price. The right to sell to the government is allocated to individual farmers through a kind of quota system. Under this system, the quantity procured by the government accounted for about 20 percent of the total crop. The government uses the rice it buys for military and other government purposes, or sells it back into the market at prevailing market prices. This program has been evolving rapidly.

The ban on rice imports was lifted and other barriers were lowered in 1995 as Korea began to comply with the URAA. The minimum-access provisions of the URAA required Korea to gradually expand imports of rice from 1 percent of base-period domestic consumption in 1995 to 4 percent by 2004. The minimum-access quantities themselves have been too small to have any measurable impact on the domestic market, especially as imports have been administered to favor the importation of rice for processing (Choi and Sumner 2000).

South Korean import data in Table 5.1 reflect the tight import controls on rice, the gradual relaxation of barriers for meat, soybeans, and barley, and the openness to importation of the other grains. South Korea is a major importer of agricultural products despite high protection for rice and several other commodities.

Agricultural Productivity Growth

In keeping with the goal of achieving self-sufficiency in rice, one major undertaking included the introduction of the high-yielding but low-quality variety *Tongil.* First introduced in 1975 with an intense government campaign, by 1985 it occupied half the total rice area. However, *Tongil* rice disappeared rapidly in the early 1990s, as incomes and demand for quality increased and government rules were relaxed.

In response to high price incentives and R&D efforts (discussed in detail in the following sections), rice yields increased by about 50 percent in three decades. Per-hectare yields of milled rice rose from 3.3 tons in 1970 to 5.0 tons in 2000. The annual rate of total factor productivity growth for rice from 1993 through 1997 was between 7 and 8 percent (Kwon and Lee 2001). Yet, despite yield and other productivity growth, the cost of producing rice has remained high. Korean production costs are about five times higher than those in California, which produces a similar quality of japonica rice (Cooperative Extension Service, University of California, Davis 1998). Implicit land rental costs account for 42 percent of production costs in Korea, and labor accounts for another 24 percent (Kwon and Lee 2001). Relatively high wages compared with most other Asian rice-producing countries, and high labor-to-land ratios compared with the United States and Australia, contribute to high costs relative to other major rice-growing regions. Of course, the very high land prices reflect high domestic prices relative to nonland variable costs.

Partial productivity measures also show rapid growth for other commodities over the past 30 years. For example, crop yields have increased rapidly, and milk yield grew from 5.0 metric tons per head in 1970 to 7.9 metric tons per head in 2000. Overall, the total real value of agricultural output grew by 110 percent over the 30-year period because of both productivity growth and a shift across commodities, while both land and labor use declined substantially. Real output per unit of land increased by 260 percent, and real output per unit of labor increased by 450 percent between 1970 and 2000.

South Korean Agriculture in Transition

The URAA stimulated many changes in South Korean agriculture. For the first time, the Korean rice industry has faced international competition. This shift in policy has had ramifications throughout agriculture as farmers attempt to improve productivity and search for commodities that may be competitive with imports. Some adjustments have been aimed at improving productivity in rice farming. The Korean government initiated a series of efforts to improve institutional arrangements in areas such as farmland ownership, domestic rice subsidy programs, marketing and distribution arrangements, and cooperatives. In 1992, Korea also began a decade-long rural restructuring project that allocated $40 billion to farmers and rural areas. This infusion of public resources into agriculture was significant. However, the most important impetus for transition came from individuals' anticipation of market opening and adjustments to meet that challenge (Sumner, Lee, and Hallstrom 1999). We now turn to how R&D fits into this picture of Korean agriculture in rapid transition.

Institutional Arrangements for Agricultural R&D

The modern Korean agricultural R&D system is about 40 years old. There have been a number of changes over time, but the basic structure has remained in place. Agricultural research and development follows many of the familiar patterns of funding and performance seen in other countries. However, compared with most other OECD members, the South Korean institutions are relatively new, and the R&D situation, as with much else in South Korean agriculture, has been evolving rapidly.

Public funding for agricultural research now follows three channels:

1. The Office of the Prime Minister provides funding through research councils that support the basic staff and core expenditures of the government-supported research institutions.

2. Specific ministries, mainly the Ministry of Agriculture and Forestry (MAF), and administrations, mainly the Rural Development Administration (RDA), support their own intramural research institutions and provide project funds for government-supported institutes, universities, and private research institutions.

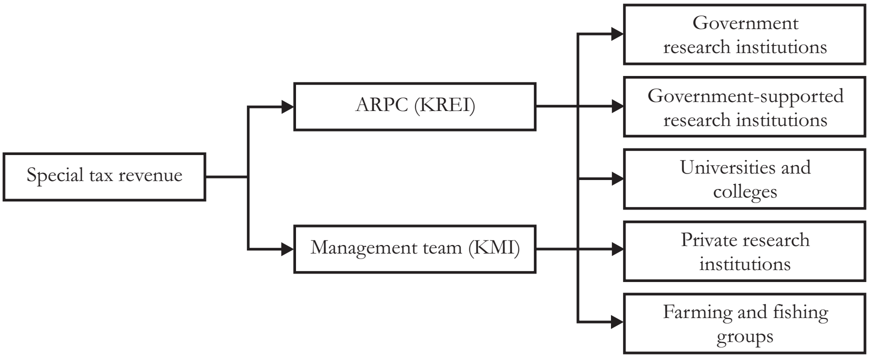
3. Science funds not tied directly to agriculture are provided to universities and public and private research institutions for more-basic research.

The RDA is the largest source of public funding for agricultural R&D. It was created in 1962 and is a separate, autonomous unit within MAF. MAF, together with the Ministry of Maritime Affairs and Fisheries, sets general directions for agricultural R&D, then MAF and RDA request funds for the research budget, and the Planning and Budget Agency modifies the request and coordinates the overall Korean government budget.

Government research institutions in agriculture, forestry, and fisheries include 46 national and public research institutions and 4 government-supported research institutions (Ministry of Science and Technology 2001). RDA, the largest R&D agency in the agricultural sector, operates 10 intramural research institutes. When the RDA was established in 1962, it had 12 intramural research institutes; this number reached 19 by the early 1990s but fell back to 12 with reform in 1994. The most significant consolidation in 1994 was the creation of the National Institute of Agricultural Science and Technology through the merger of 4 independent institutes (the Institute of Agricultural Science, the Agricultural Chemicals Research Institute, the Agricultural Genetic Engineering Institute, and the National Sericulture Entomology Research Institute).

South Korean data distinguish between units of the government that are under the direct supervision of a specific ministry, such as the intramural institutes under the RDA, and other publicly funded units that are collectively known as public nongovernmental enterprises. Before 1999, each institute had belonged to the corresponding ministry. Since then, government-supported research institutes have been placed under the Office of the Prime Minister rather than under individual ministries. This reform was designed to enhance the independence of the institutes, encourage joint research, and facilitate the sharing of information among institutes. Under the new system, each government-supported institution competes with external research institutions, such as universities or private research bodies, for project funds other than basic salaries and basic costs, which are provided by the government. The Korea Rural Economic Institute, the Korean Maritime Institute, the Food Research Institute, and the Korean Research Institute of Bioscience and Biotechnology all report to the Office of the Prime Minister.

Figure 5.1 Korea: Distribution of research funds from the special tax for agricultural and rural development



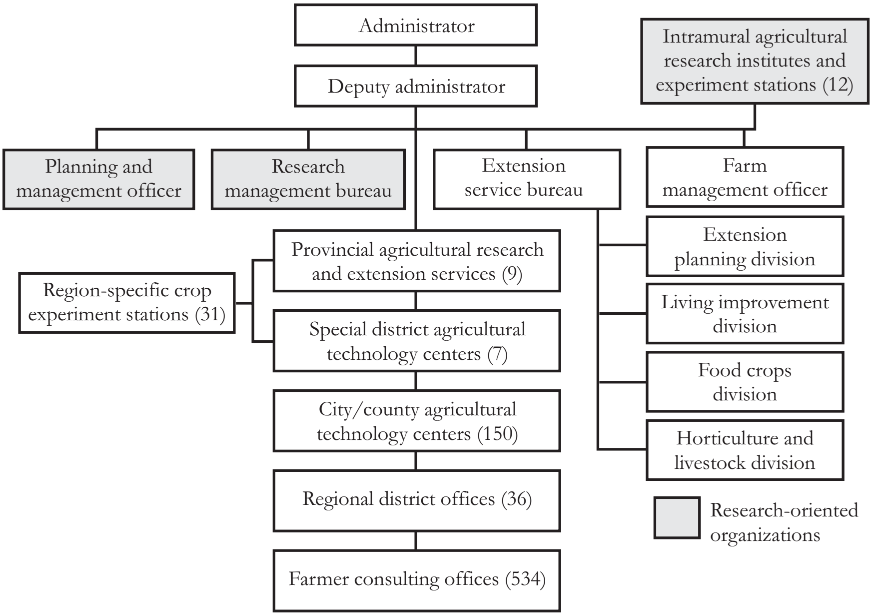
Source: Compiled by authors.

MAF provides some research funds directly to the research entities that are separate from RDA's budget. MAF's research fund is allocated competitively, and the government-supported research institutes win the largest share of these grants. Since 1994, MAF has provided additional competitive research grants drawn from the special tax for agricultural and rural development, administered by the Agricultural R&D Promotion Center (ARPC), an affiliate of the Korea Rural Economic Institute.[1] Figure 5.1 shows the flow of funds from the 1994 special tax.

The Ministry of Maritime Affairs and Fisheries now guides research policy for fisheries and maintains the Korea Maritime Institute (KMI), which also funds competitive grants. The Forestry Administration, within MAF, operates two intramural research institutes.

Rural and agricultural extension services have been provided primarily by the RDA rather than by universities or by state or local governments. The extension service was introduced in the late 1950s to promote the dissemination of agricultural production technology. RDA took over the extension role when it was established in 1962. The rate of adoption of modern agricultural practices was very low throughout the 1960s and 1970s, and extension was an important tool for increasing productivity. Because the government's focus during this period was on increasing rice self-sufficiency, the extension service concentrated on disseminating new high-yielding varieties and other high-productivity technology. The extension service still accounts for a major part of the RDA budget. Figure 5.2 illustrates the basic organization of agricultural extension in South Korea.

Figure 5.2 Korea: Rural extension organizations—Rural Development Administration, 2000



Source: Compiled by authors.

Note: Figures in parentheses indicate number of stations, centers, offices, or services.

The National Agricultural Cooperative Federation (NACF) has also exerted a significant influence on agricultural R&D. NACF operates as a major marketing cooperative, but it is also a farm input supplier, a financial institution, and an insurance company. It has been a powerful political force and has had quasi-governmental authority in implementing farm programs. NACF also operates an agricultural college and has performed extension services. However, NACF has not been as influential in extension as RDA.

The role of universities in Korean agricultural R&D resembles that of institutions in Australia and several European countries more closely than that of universities in the United States. The total number of universities conducting agricultural research is not available, but about 35 university research institutes are devoted to agriculture, forestry, or fisheries (Ministry of Science and Technology 2001). University funding for agricultural research is limited, staff teaching loads are high, and support for research must be garnered from relatively short-term grants. As is discussed below, there have been some increases recently in the competitive funds available from government sources for university research related to agriculture, but these funds remain small relative to the funding for government researchers.

Private companies are important in certain parts of the formal R&D effort, but we have relatively little information about their work; thus they are necessarily underrepresented in the discussion that follows. Overall, companies in the agriculture, forestry, and fisheries sectors operate ten formal research institutes (Ministry of Science and Technology 2001). Companies account for a significant share of the total formal outlays on agricultural R&D—about 16 percent. (For information on private agricultural R&D in other parts of Asia, see Pray and Fuglie 2001.) Individual farms and small local entrepreneurs devote much effort to innovation in agriculture. As farm size, crop mix, costs of labor, and other aspects of agriculture have changed rapidly, farmers have invested in, developed, and adopted innovations. Such innovation requires sustained investment of resources, but unfortunately such R&D on farms is difficult to measure, and we have not been able to document it thoroughly.

The Provision of Agricultural R&D Services

This section reviews evidence on budget trends and a number of other characteristics of Korean R&D providers. Because of data limitations, we focus more on government and university providers than on the private sector.

Expenditures of R&D Providers

Agricultural R&D in Korea is performed by several types of research organizations: government agencies and government-supported research institutions, public and private universities and colleges, and private companies, including cooperatives.

Table 5.2 provides shares of R&D expenditures by research provider from 1995 to 2000. Since 1995 the university and college share has grown from about 12.1 percent to almost 20.8 percent of the total, while the share of companies has fallen from 17.5 percent to 12.6 percent. Government R&D organizations and government-sponsored institutes have conducted the bulk of the research every year, ranging from 70.4 percent in 1995 to 63.7 percent in 1999 before increasing to 66.6 percent in 2000. Company data are not available prior to 1995, so it is not possible to calculate comparable shares for earlier years.

Table 5.3 contains more detail on R&D expenditures since 1978 for government and university research. Table 5.3 provides the data in Korean won; Appendix Table 5A.1 converts data to international dollars using a purchasing power parity exchange rate. The data are complete for government and government-supported research institutes for this period and provide information on university

Table 5.2 Korea: R&D expenditures on agriculture, forestry, and fisheries by type of research entity, 1995–2000 (percent)

Year	Government institutes	Universities and colleges	Companies	Total
1995	70.4	12.1	17.5	100
1998	67.4	17.3	15.3	100
1999	63.7	20.1	16.2	100
2000	66.6	20.8	12.6	100

Source: Ministry of Science and Technology and Korea Institute of S&T Evaluation and Planning 2001.

expenditures from 1978 to 1988 and from 1995 to 2000. R&D expenditures, expressed in real terms using the GDP deflator, have risen substantially. The bulk of research has always been conducted at national and public research institutes, especially the RDA. The government-supported institutes, which have more autonomy from MAF, have accounted for an important part of the research expenditures. Over the period shown in Table 5.3, the share of government research done by the national and public institutes has fluctuated, but it remained around 15 percent before declining to about 11.5 percent for the last three years in our series.

University expenditures grew from about 13.5 billion won for the 1978–79 average to about 35 billion won in 1988, while R&D expenditures in government research institutes were comparatively stagnant in real terms. (We find the huge measured drop in public university expenditures from 1978 to 1979 inexplicable and therefore use an average of the two years.) Overall, the share of research expenditures by universities doubled from about 10 percent of the (noncompany) total during the 1978–79 average to about 20 percent in 1988.

The decade from 1988 to 1997 saw very rapid overall growth in university and government research, with university expenditures remaining a relatively constant proportion. Reflecting URAA initiatives, government expenditures doubled in real terms from 1991 to 1993 and continued to grow gradually thereafter. Even the financial crisis of 1998 did not curtail research substantially.

Research Orientation

It is always difficult to classify R&D projects. Classification into "applied" versus "basic" research or "development" efforts is to some degree arbitrary. Here we report the classifications used by the institutions themselves. The research expenditures by public research institutions in agriculture, forestry, and fisheries in 2000 suggest that about half of all research is applied. The remaining half is divided almost evenly between basic and development research. Government-supported agricultural research institutions spend a higher proportion of their funds on development research than do the national and public research institutions (Ministry

Table 5.3 Korea: R&D expenditures on agriculture, forestry, and fisheries by type of research entity, 1978–2000 (billion 1999 won)

	Research institutes			Universities and colleges			Companies			
Year	Total	National and public	Government-supported	Total	National and public	Private	Total	Government-invested	Private	Total
1978	107.4	99.6	7.8	21.0	18.1	2.9	NA	NA	NA	128.4
1979	150.0	129.8	20.2	6.6	4.3	2.3	NA	NA	NA	156.6
1980	114.6	95.5	19.1	12.5	10.7	1.8	NA	NA	NA	127.1
1981	93.0	74.7	18.3	7.7	7.1	0.7	NA	NA	NA	100.7
1982	112.9	95.3	17.6	18.3	14.6	3.7	NA	NA	NA	131.2
1983	93.0	86.2	6.8	15.8	11.9	3.9	NA	NA	NA	108.8
1984	107.9	87.9	20.0	23.1	17.9	5.3	NA	NA	NA	131.0
1985	106.2	88.2	18.0	21.3	17.6	3.7	NA	NA	NA	127.5
1986	118.8	99.9	18.9	36.5	29.4	7.1	NA	NA	NA	155.3
1987	133.1	113.9	19.2	32.1	23.5	8.5	NA	NA	NA	165.2
1988	136.3	115.1	21.2	35.4	30.1	5.3	NA	NA	NA	171.7
1989	142.7	121.2	21.5	NA	NA	NA	NA	NA	NA	NA
1990	166.6	130.8	35.8	NA	NA	NA	NA	NA	NA	NA
1991	166.7	132.2	34.5	NA	NA	NA	NA	NA	NA	NA
1992	202.0	168.6	33.4	NA	NA	NA	NA	NA	NA	NA
1993	327.2	290.1	37.1	NA	NA	NA	NA	NA	NA	NA
1994	293.8	252.2	41.6	NA	NA	NA	NA	NA	NA	NA
1995	335.5	296.9	38.6	57.7	35.1	22.7	83.5	8.0	75.5	476.7
1996	346.5	299.0	47.5	86.5	44.0	42.5	NA	NA	NA	433.0
1997	372.3	321.9	50.4	83.2	45.1	38.1	97.1	8.3	88.8	552.6
1998	336.3	295.4	40.9	86.5	52.5	34.0	76.1	10.5	65.6	498.9
1999	309.9	278.4	31.5	102.8	65.9	36.9	83.1	12.5	70.7	495.8
2000	330.4	287.9	42.5	103.4	65.2	38.2	62.7	NA	NA	496.5

Source: Ministry of Science and Technology and Korea Institute of S&T Evaluation and Planning 2001.

Notes: Data were converted to 1999 won using a GDP deflator. NA indicates data not available.

of Science and Technology 2001). We have no information on how the Korean classification system compares in practice with those in other countries.

Consistent with national agricultural policy, research on rice has been the central focus of agricultural R&D in South Korea. As a result, a number of high-yielding cultivars have been developed. In 2000, 99.2 percent of all paddy land was planted to cultivars developed by RDA (Rural Development Administration 2000). Research on rice, however, declined as a share of total research in the 1990s. Research on nonrice crops, including fruits and vegetables, specialty crops, livestock, and flowers, has increased (J. Park et al. 2000).

The amount of research devoted to each commodity may also be observed from an analysis of research papers written by the RDA staff. In 1958, about 53 percent of these research papers were devoted to grains (37 percent to rice and another 16 percent to other grains). This percentage fell to about 33 percent in 1970 and then rose back to about 45 percent in 1980 and 1990 (Table 5.4). It declined to about 40 percent by 1995 and to 31 percent by 1998. Considering rice alone, the share of research papers increased from about 21 percent in 1970 to 30 percent in 1980 before falling back to about 17 percent in 1998. The continuing high publication share for nonrice grains is puzzling, given the unimportance of those crops in South Korean agriculture. It may be driven by three factors: the relevance of research on other grains to rice applications; a prevalence of researchers trained in an era when other grains were more important; and the fact that many researchers have studied in places such as the United States or Australia, where other grains are important, and thus their early publications relate to these other crops. There is considerable variability in some of the data on other crops, but two other trends stand out in Table 5.4. First, the share of publications on livestock research dropped substantially, from a high of almost 35 percent in 1970 to less than 20 percent in 1998. Second, the share of publications devoted to vegetable crop research increased from about 6 percent in 1970 to 15.5 percent in 1998.

Table 5.4 Korea: Percentage of RDA research papers by commodity group, 1970–98

Year	Rice	Grains	Specialty crops	Vegetables	Fruits	Livestock	Flowers	Forestry	Other
1970	21.1	11.5	1.9	5.8	12.0	34.6	3.8	0.0	9.3
1980	30.3	15.2	4.3	8.7	4.3	26.1	4.3	0.0	6.8
1990	26.0	20.0	7.3	7.3	4.0	22.7	5.3	2.0	5.4
1995	21.5	18.1	5.1	14.7	11.0	20.9	4.0	0.6	4.1
1998	17.0	13.7	8.2	15.5	9.5	19.5	8.6	0.3	7.7

Sources: Complied by authors from Rural Development Administration 1999 and S. Park et al. 2000.

Another indicator of the current orientation of R&D in Korea is the distribution of ARPC funds. About half of these funds are allocated to projects classified as "advanced technology," with a quarter allocated to overtly applied projects in the field or projects involving farmers; the final quarter goes to projects classified only as "national priority." The precise meanings of these categories are difficult to discern, but the general thrust is that at least half these funds are allocated to relatively basic research efforts as opposed to field studies (MAF 1999).

Agricultural R&D Personnel Qualifications and Orientation

The total number of researchers and other staff at government agricultural research institutions in South Korea has changed little since 1978. The total number of staff was about 4,546 in 1978 and grew to 5,108 by 2000. However, the proportions of staff in each job classification changed substantially. In 1978 there were 0.72 technicians and 0.87 support staff per researcher. By 1999 those ratios had fallen to 0.5 technicians and 0.33 support staff per researcher (Ministry of Science and Technology 2001).

Between 1978 and 2000, however, there were large shifts in the reported numbers in each classification. Some of these changes likely occurred as a part of institutional reorganizations. For example, the total reported staff increased from 5,597 in 1992 to 8,184 in 1993. This change is consistent with the increase in R&D expenditures for those years, shown in Table 5.3. However, personnel data show that the staff numbers declined to 6,399 in 1994. By 1996 the total number of staff had fallen by another 20 percent, with the number of researchers accounting for about half the decline. Another drop of about one-sixth of the total staff occurred in 1997, but on this occasion most of the staff cuts were in the technician category. Expenditures grew during this period; even allowing for real salary increases and additional budgets for supplies and equipment, it is difficult to understand how the staff reductions are consistent with the expenditure increases. Thus, reported staff numbers do not seem to reflect reductions in the actual amount of research effort.

Table 5.5 summarizes the share of researchers, including support staff, across research institutions for 2000. These data show that university and college researchers account for a significantly higher share of total research personnel than of total R&D expenditures (Table 5.3). This disparity reflects the part-time nature of academic research and a relative lack of research facilities.

In 1978 only about 5 percent of researchers held Ph.D.s and another 15 percent held master's degrees. By 1999, 38 percent of researchers held Ph.D.s, and another 49 percent held master's degrees (Ministry of Science and Technology 2001).

Table 5.5 Korea: Agricultural researchers by type of research entity, 2000

Type of research entity	Number of researchers	Percentage of total researchers
Government research institutes	5,108	53.3
Universities and colleges	3,255	34.0
Companies	1,216	12.7
Total	9,579	100.0

Source: Ministry of Science and Technology and Korea Institute of S&T Evaluation and Planning 2001.

Data on numbers, broad topics, and qualifications of agricultural researchers in colleges and universities and in companies are provided in Table 5.6. Universities and colleges had 3,255 staff members who devoted some time to agricultural research in 2000. Of these, two-thirds were classified as crop agriculture and forestry researchers, and another 20 percent, approximately, as animal husbandry researchers. About two-thirds of these researchers have Ph.D.s, and almost all the rest have master's degrees. One concern with the data on university and college researchers is that we do not know the extent of their research commitment. For example, we do not know what portion of their time these individuals devote to research relative to teaching and other responsibilities. Nor do we know how their research is directed to specific topics.

Of 1,216 company researchers, about two-thirds work in crop agriculture and forestry, with another one-sixth in animal husbandry. However, only 15 percent of the company researchers have Ph.D.s, and only about half have any type of graduate degree. These differences in qualifications suggest significant differences in the nature of academic and company research.

Table 5.6 Korea: Education levels of agricultural researchers in universities and companies, 2000

Research focus	Ph.D.	M.Sc.	B. Sc.	Other	Total
Universities and colleges					
Agriculture and forestry	1,490	560	140	41	2,231
Animal husbandry	430	121	8	13	572
Fisheries and marine	273	37	5	0	315
Other	99	34	1	3	137
Total	2,292	752	154	57	3,255
Companies					
Agriculture and forestry	116	294	382	28	820
Animal husbandry	30	96	73	2	201
Fisheries and marine	6	10	18	1	35
Other	7	30	88	35	160
Total	159	430	561	35	1,216

Source: Ministry of Science and Technology and Korea Institute of S&T Evaluation and Planning 2001.

As noted earlier, the extension service in Korea has been a branch of the RDA for about four decades. The number of extension personnel was relatively stable (between 6,000 and 8,000) from 1965 through 1997. The size of the extension staff doubled from 1963 to 1965 as the result of a presidential intervention. President Park, who took an active personal interest in rural issues and food security, decided that about 3,000 individuals who had been employed under contract to distribute *Tongil* rice varieties to farmers should be incorporated into the extension service. This shift more than doubled the number of extension workers in a two-year period. However, in 1997, most extension workers employed by the central government were transferred to local government appointments. The number of extension workers dropped from 6,839 in 1997 to 5,545 in 1998 and 5,032 in 1999, a 27 percent decrease in two years (Rural Development Administration 1998, 1999, and 2000; KREI 1999).

Funding of Agricultural R&D in Korea

Funding for agricultural R&D in Korea has grown dramatically in both nominal and real terms over three decades, but with some fluctuations. Research institutions evolved significantly in the 1990s as substantial new resources were added.

Agricultural R&D Intensity

We do not have a complete history of total R&D expenditures for South Korea because data on research by companies are limited. However, using the data from Table 5.3 together with agricultural GDP data, we find that agricultural R&D intensity has grown rapidly for many years. The sum of university and government R&D was 0.68 percent of agricultural GDP in 1988, growing to 1.68 percent by 1995 and to 1.82 percent in 1997. This measure of research intensity has changed little since. Government agricultural R&D has also grown rapidly. In particular, from 1992 to 1995, in response to the pressure created by URAA, government agricultural R&D rose from 0.81 percent to 1.44 percent of agricultural GDP.

Table 5.7 shows two measures of relative intensity of agricultural R&D since 1994. Total R&D expenditures have risen from about 9 trillion won in 1994 to over 14 trillion won in 2000 (in 1999 prices). After a dip during the financial crisis in 1998, total R&D expenditures jumped by 2.9 trillion won in 2000. Agricultural R&D followed a similar pattern, except that the dip in 1998 was less severe, and expenditures actually declined in 2000 even in nominal terms. Agricultural R&D remained at around 4.5 percent of total R&D (except in 1996) before falling to 3.5 percent in 2000. This percentage is far less than the share of agriculture in the South Korean economy. Agriculture, forestry, and fisheries accounted

Table 5.7 Korea: Agricultural R&D expenditure and research intensity, 1994–2000 (1999 prices)

	R&D expenditure on agriculture, forestry, and fisheries			Gross domestic product of agriculture, forestry, and fisheries			Total R&D expenditure	
Year	Billion won	Million U.S. dollars	Percentage of total R&D expenditure	Billion won	Million U.S. dollars	Percentage of total R&D expenditure	Billion won	Million U.S. dollars
1994	414.4	349	4.4	25,037.0	21,060	1.7	9,366.8	7,879
1995	476.7	401	4.6	25,865.2	21,757	1.8	10,456.0	8,795
1996	433.0	364	3.7	26,053.8	21,916	1.7	11,597.2	9,755
1997	552.6	465	4.4	25,072.4	21,090	2.2	12,595.1	10,595
1998	499.0	420	4.5	21,621.5	18,187	2.3	11,152.8	9,381
1999	512.4	431	4.3	24,481.5	20,593	2.1	11,921.8	10,028
2000	496.6	418	3.5	24,241.3	20,391	2.0	14,065.3	11,831

Source: Ministry of Science and Technology and Korea Institute of S&T Evaluation and Planning 2001.

Note: Data were converted to 1999 won using a GDP deflator, and to U.S. dollars using a 1999 purchasing power parity (PPP) exchange rate ($1=1,188.82 won).

for 6.2 percent of the national earnings in 1995 and 4.6 percent in 2000. As a share of the labor force, agriculture is even more important. Agriculture accounted for 12.4 percent of the labor force in 1995 and 10.9 percent of the labor force in 2000.

One interpretation of these figures is that Korea has underinvested in agricultural research relative to other sectors of the economy. However, such a conclusion would be premature without information on the actual or prospective rates of return to investments in agricultural R&D relative to R&D in other parts of the economy. There are two reasons why agricultural R&D may offer lower rates of return than R&D in other sectors for a given level of current intensity. First, given the difficulty in appropriation of benefits from agricultural R&D oriented to farm production, there is an in-principle case for much of this research to be supported by public funds. However, government funding makes it harder to link funding to performance relative to investments by private firms for their own expected profit. Thus, even though the *potential* payoff may be higher, the *realized* payoff to agricultural R&D may be lower, and the lower research intensity follows as an appropriate consequence. These theoretical arguments notwithstanding, evidence generally supports the view that public agricultural R&D has a comparatively high payoff (Alston et al. 2000). Second, because the payoff to R&D investments is achieved only with a significant time lag, it may be more appropriate to compare R&D investments now to the projected future size of the agricultural economy. That is, investments in R&D in 2005 are likely to be applied in Korea in 2010 or later. This makes the relative research intensity measures misleading for industries in which the projected relative shares are changing rapidly.

Agricultural R&D Funding Sources and Flows

Data on company funding of R&D are not available, but Table 5.3 provides the data on company performance of R&D, and we believe that almost all of those funds spent by private research institutions were provided by private companies themselves. Also, recent data show that little company funding now flows to government institutions (Ministry of Science and Technology 2001).

The composition of funding for government agricultural research institutions had one major fluctuation in the past 30 years. From 1984 to 1996 a significant share of the cost of the research performed by these organizations was covered by private funds. Private support for research at government institutions grew from almost nothing in the early 1980s to between 10 and 20 percent for a decade before declining gradually to almost zero again by 1997 (Ministry of Science and Technology 2001).

MAF, RDA, and ARPC are now the three main agricultural funding agencies for agricultural R&D projects. In addition, the Ministry of Maritime Affairs and Fisheries and the Ministry of Finance and Economy provide funds to the R&D institutions with mandates in the corresponding areas.

MAF finances mainly policy-oriented R&D in agriculture. Previously the research funds from MAF were available solely to government-supported research institutions such as the Korea Food Research Institute (KFRI) and the Korea Rural Economic Institute (KREI), but these funds are now allocated through competitive grants among government-supported research institutions, universities and colleges, and private companies. Most of the RDA's research budget is allocated to ten intramural research institutions under RDA. However, a small share is distributed to other public and private research institutions and to universities and colleges in the form of long-term joint research projects with RDA. The Forestry Administration mainly provides research funds to its own research arms—the Forestry Research Institute and the National Arboretum. Forestry research is also conducted by the KREI. The Ministry of Maritime Affairs and Fisheries research funds are made available to the Korea Ocean Research and Development Institute and the KMI.

As noted above, the significant changes in agricultural R&D policy that took place in 1992 and 1994 were motivated by international trade issues. As it became clear that the URAA would create some additional pressure to import, the Korean government responded with substantial new agricultural R&D funding. Two new programs were initiated, with the stated goals of strengthening agricultural competitiveness and improving the quality of rural life. The Agricultural and Rural Structural Improvement Program, which ran from 1992 to 1998, devoted 33,400 billion won to R&D. Of this total, about 6 percent each was devoted to forestry and fisheries, about 35 percent was devoted to rice, and about 12 percent to livestock R&D. Only 4 percent of the funds were devoted to horticulture (MAF 2000). This allocation can be understood as a response to the real threat that potential imports might pose for domestic rice production, but it was not consistent with the ever-growing importance of horticulture in Korean agriculture. Given that Korean rice prices are about four times higher than border prices, R&D could do little to protect domestic rice production and land prices that rely on high domestic prices if the border were opened significantly. Competitiveness is different for significant parts of the Korean horticultural industry. Given the premium on freshness, the uniqueness of the Korean market, and the high cost of transportation, R&D has the potential to help some segments of the Korean horticultural industry to compete effectively with imports.

The second response to the URAA was the special tax for rural and agricultural development, which was scheduled to provide about $45 billion won for R&D until 2004. The agricultural research fund is managed by the ARPC. With the establishment of the Ministry of Maritime Affairs and Fisheries in 1997, the fisheries section of ARPC was transferred to an R&D Management Team for Fisheries under the Korea Maritime Institute. These funds are allocated to government-supported research institutions, private research institutions, and universities and colleges.

Interestingly, the ARPC was created as a unit under KREI in 1995 and is staffed and managed mainly by economists. The idea behind this institutional arrangement, under which the allocation of scientific R&D funds was explicitly the role of economics staff, was to tie the allocations of R&D funds more directly to the economic issues of importance to agriculture in Korea (KREI 1997). Furthermore, one might expect that formal economic principles and analysis would play a more significant role in the allocation of funds. However, it is not clear that such approaches are in fact used in the allocation process. The procedures used by ARPC seem to be much the same as other peer-reviewed competitive research programs.

Summary and Conclusion

The Rural Development Administration is both the largest funder and the largest provider of Korean Agricultural R&D and extension. Rice-related technological development continues to receive substantial research resources. Over the past 30 years, with strong financial and political support, the RDA bred a number of high-yielding rice cultivars that have been widely used in Korea.

More recently, in response to URAA, the government created a new funding source and a new agency, APRC, for agricultural R&D. The special tax for rural development funds was scheduled to end in 2004 but was recently extended until 2014. Many countries, including the United States, have responded to competitive pressures in agriculture with additional commodity subsidies and attempts to increase protection. Faced with WTO limits on direct subsidies and with declining border protection, Korea opted to devote substantial new resources to R&D and other productivity-enhancing public-good investments.

The additional funds available through ARPC provided universities and the private sector an expanded opportunity to participate in agricultural research. A growing problem, however, is coordination in setting research goals and priorities. This issue applies in most countries, and is probably even more troublesome in places such as the United States, where much agricultural R&D is funded by states and performed by individual universities.

As Korea grapples with the lack of international competitiveness of some important industries, it must look to rapid changes in farm size, the commodity mix on farms, demographic and human capital transformations, and innovative technologies. Obviously, these issues are not unique to Korea, but Korea may be ahead of most other countries in facing these questions in the context of an incredibly rapid transformation of the economy. By all accounts, Korean farm leaders expect the border to open, and they expect major changes.

Given the major adjustments facing Korean agriculture, the potential payoff for some new R&D investments is less clear. R&D investments must be applicable to those commodities, farm sizes, organizations, and regions that are likely to remain viable for 5 or 10 years from the time of the investments. Careful economic analysis may show that R&D investments would have a higher payoff if they ignored some of the productivity concerns of hundreds of thousands of small rice farms that might be already gone by the time research results were available for adoption. Furthermore, given terrain that makes tiny plot sizes the only possibility in much of the country, the payoff might also be higher for R&D investments that focused mainly on regions of the country that are likely to remain in commercial agriculture. It may be counterproductive to dilute the Korean R&D budget by investing in marginal areas that are unlikely to remain in agriculture and can never be made competitive in rice production. The challenge is how to maintain a political consensus to support agricultural R&D if it opts to neglect parts of the country and many of the current farms.

The objective of a more productivity-based R&D policy may be achieved by tying agricultural R&D funding measures to broader funding for aid in the transition out of farming or to shifts to other commodities. A budget for aid to rural areas and residents could be made broadly available, with self-selection into various arms of a program that included agricultural R&D, aid for rural schooling and other human capital development, and aid for rural nonfarm infrastructure. This effort could smooth the process of adjustment to more open markets for farm commodities and mitigate losses for some commodities and regions.

The transition facing Korean agriculture suggests that, more than in most countries, effective R&D investment policy must be developed in the context of economic analysis of the effects of changes in other economic policy that affect agriculture. Korean officials recognize this fact, but implementation remains a challenge.

Appendix Table 5A.1 Korea: R&D expenditures on agriculture, forestry, and fisheries by research entity, 1978–2000 (million 1999 international dollars)

	Research institutes			Universities and colleges			Companies			
Year	Total	National and public	Government-supported	Total	National and public	Private	Total	Government-invested	Private	Total
1978	90.4	83.8	6.6	17.7	15.2	2.4	NA	NA	NA	108.0
1979	126.2	109.2	17.0	5.6	3.7	1.9	NA	NA	NA	131.8
1980	96.4	80.3	16.1	10.5	9.0	1.5	NA	NA	NA	106.9
1981	78.3	62.9	15.4	6.5	5.9	0.6	NA	NA	NA	84.8
1982	94.9	80.1	14.8	15.4	12.3	3.1	NA	NA	NA	110.3
1983	78.2	72.5	5.7	13.3	10.0	3.3	NA	NA	NA	91.5
1984	90.8	74.0	16.8	19.4	15.0	4.4	NA	NA	NA	110.2
1985	89.3	74.2	15.1	17.9	14.8	3.1	NA	NA	NA	107.2
1986	99.9	84.0	15.9	30.7	24.8	5.9	NA	NA	NA	130.6
1987	119.9	95.8	16.1	27.0	19.8	7.2	NA	NA	NA	138.9
1988	114.7	96.8	17.9	29.7	25.3	4.4	NA	NA	NA	144.4
1989	120.1	102.0	18.1	NA	NA	NA	NA	NA	NA	NA
1990	140.2	110.1	30.1	NA	NA	NA	NA	NA	NA	NA
1991	140.2	111.2	29.0	NA	NA	NA	NA	NA	NA	NA
1992	169.9	141.8	28.1	NA	NA	NA	NA	NA	NA	NA
1993	275.2	244.0	31.2	NA	NA	NA	NA	NA	NA	NA
1994	247.1	212.1	35.0	NA	NA	NA	NA	NA	NA	NA
1995	282.2	249.8	32.4	48.6	29.5	19.1	70.2	6.7	63.5	401.0
1996	291.5	251.5	40.0	72.8	37.0	35.8	NA	NA	NA	364.3
1997	313.1	270.7	42.4	70.1	37.9	32.0	81.7	7.0	74.7	464.9
1998	282.9	248.5	34.4	72.8	44.2	28.6	64.0	8.8	55.2	419.7
1999	260.7	234.2	26.5	86.5	55.4	31.1	70.0	10.5	59.5	417.2
2000	278.0	242.2	35.8	87.0	54.8	32.2	52.7	NA	NA	417.7

Source: Ministry of Science and Technology and Korea Institute of S&T Evaluation and Planning 2001.

Notes: Data were converted from Korean won to U.S. dollars using a 1999 purchasing power parity (PPP) exchange rate ($1=1,188.82 won). NA indicates data not available.

Note

1. The special tax for agricultural and rural development (first introduced in 1995 for a 10-year period but now extended to 2014) is a tax earmarked for agricultural development, the enhancement of agricultural competitiveness, and the improvement of rural living conditions and rural welfare. It was implemented as a surtax or surcharge on a number of existing taxes such as income tax, corporate tax, and import tariffs. The surcharge is typically in the range of 20 percent, such that if the income tax rate, for example, is 30 percent, the special tax constitutes a further 6 percent. The total annual revenue target for the tax is around 1,500 billion won (about US$1.5 billion).

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Chapter 6

Bangladesh: Uncertain Prospects

Raisuddin Ahmed and Zahurul Karim

Introduction

Bangladesh is one of the most impoverished countries in the world. Agriculture remains the primary source of income for about 60 percent of the population. Agricultural growth therefore holds the key to the nation's pervasive poverty. So formidable are resource limitations, the climatic and environmental conditions, and the complexity of the country's agricultural institutions that the pace of agricultural growth rests heavily on gains in productivity, especially those gains arising from research and development. Bangladesh's achievements in agriculture and rural development have been significant since independence in 1971, and research and development have played a vital role in this achievement.

This chapter focuses on the evolution of research policies and institutions, the priority given to agricultural research in resource allocation, the impact of agricultural research on productivity, and a vision for the future role of research.

Generally, *research and development* means not only the generation of applicable knowledge or superior products, but also the transfer of such knowledge or products to potential users. In this chapter, however, the term refers specifically to the generation and development of knowledge or products to usable forms; we exclude extension and other activities associated with the transfer of research results.

Structural Background

Agriculture and the Economy

The transformation of Bangladesh's economy, measured by changes in the sectoral shares of gross domestic product (GDP), is shown in Table 6.1. This structural

Table 6.1 Bangladesh: Structural change in the economy, 1975–2004

Indicators	1975	1985	1995	2000	2004
Share of gross domestic product (percent)					
Agriculture	62.0	41.8	30.9	27.8	21.0
Industry	11.6	16.0	17.6	18.2	24.0
Manufacturing	7.0	9.9	9.6	9.9	16.0
Construction and mining of mineral resources	4.6	6.1	7.0	8.6	8.0
Services	26.4	42.2	51.5	54.0	55.0
Share of employment (percent)	111.6	116.0	116.6	118.5	126.0
Agriculture	78.0	72.0	NA	62.5	60.3
Industry	8.0	9.0	NA	12.0	12.7
Services	14.0	19.0	NA	25.5	27.0
Per capita income (1995 U.S. dollars)	147.0	190.0	240.0	272.0	380.0
Exports as a percentage of gross domestic product	2.9	7.4	14.2	16.1	18.0
Imports as a percentage of gross domestic product	8.1	18.3	22.5	23.1	26.0

Sources: Sector shares are from World Bank, Bangladesh Country Operations Division 1996; 2000 estimates are updated from World Bank, Bangladesh Country Operations Division 1996 using BBS Labour Force Surveys and Planning Commission documents, various years. Employment statistics are calculated from data in the labor surveys of 1977, 1979, and 1993, using intercensus trend factors, and hence are less reliable than the other data in the table. The 2004 statistics are author compilations of data obtained in connection with a public expenditure review in preparation for the World Bank (Ahmed and Mudahar 2006 forthcoming).

Notes: NA indicates not available. Shares of GDP do not sum to 100 percent because categories overlap. For example, manufacturing, construction, and mining are subsectors of industry.

change clearly indicates a rapid movement away from an agriculture-dominated economy. Agriculture's share of GDP declined from 62 percent in 1975 to 21 percent in 2004, but agriculture's share of total employment has not declined as quickly. The declining share of agriculture in GDP should not be construed to reflect a diminishing role of agriculture in the overall growth of the economy or in poverty reduction. Notably, the service sector has expanded at an unusually rapid pace at this stage of economic transformation. Much of the growth in the services sector relates to the marketing and processing of agricultural products resulting from rapid commercialization and diversification in agriculture.[1] Another feature of the structural change is the extent of openness of the economy, as measured by the international trade components (exports and imports) in GDP. The sum of exports and imports constituted only 11 percent of GDP in 1975 but climbed to about 44 percent in 2004.

Poverty

Food poverty, measured by counting the number of persons consuming less than 2,212 calories per day, is especially high in Bangladesh. Most estimates from 1983–84 through 1991–92 suggest that about 50 percent of the overall population could not afford a diet meeting the caloric norm (see Ahmed, Haggblade, and

Chowdhury 2000 for a summary). Recent estimates, however, show that the average incidence of poverty might have declined slightly, to about 45 percent, between 1996 and 2000 (Sen and Mujeiri 2000). Most analysts agree that the great majority of the poor live in rural areas and that more than half the rural population live below the poverty line, compared with about one-third of urban dwellers.

Population, Land Use, and Farm Structure

In 2003, the population of Bangladesh was estimated to be 138 million, inhabiting an area of just over 50,000 square miles—of which about 22.3 million acres (69 percent of total land area) are cultivated land (FAO 2005). Competition for the use of land for agriculture, urbanization, homesteads, and infrastructure is intense; from 1983–84 through 1995–96, the cultivated area declined by 12 percent (BBS 1996). The average farm size fell from 2.26 to 1.69 acres. Because land is cultivated repeatedly within a year, the cropping intensity averages 170 percent. Rice is the dominant crop, occupying about 73 percent of the cropped area in 1996. Notwithstanding the country's large and still-growing population, the rate of population growth has fallen over time, from an average of 2.3 percent annually between 1975 and 1985 to 1.8 percent between 1985 and 1995. Since then, the annual growth rate is estimated to be 1.7 percent (World Bank 2005).

Agroecological Environment

Except for the hilly regions in the northeast and southeast, the country is mainly flat, formed at the deltaic confluence of the Ganges and the Brahmaputra and Meghna river systems. The river system, topography, rainfall, and soil types all interact to shape conditions for agricultural production. Devastating floods, severe drought, and occasional tidal ingression of saline water are quite common in Bangladesh.

Rainfall and topography are, however, two critical factors in agriculture. The normal rainfall is 2,500 millimeters per year, mostly occurring from May through September, and its distribution is more crucial in Bangladesh than the annual average. Topography generally determines how much natural protection a particular area has from floodwater. Forty percent of the cultivated land is normally inundated under 90 or more centimeters of water in peak rainy months.

Evolution of Research Institutions and Policies

The agricultural research institutions and organizations in Bangladesh are the product of a process that began in the colonial era, particularly during the years 1910 to 1940, when the British government in India introduced limited home rule, allowing participation of natives in governance (Pray 1979, 1980). Thus, the 1928 Royal Commission on Agriculture was instrumental in the establishment of the Bengal Department of Agriculture, which made some concerted efforts to establish regional experimental stations, research centers for jute and rice, and an agricultural college in Dhaka (Alim and Sen 1969).

During the Pakistani era (1947–71), a number of significant milestones enlarged the scope of agricultural research:

- A rice research institute was established in 1968, consolidating the earlier entities established for research on rice
- Commodity-specific research institutes were established, such as the Jute Research Institute, the Tea Research Institute, the Sugarcane Research Institute, and the Forest Research Institute
- The Atomic Energy Commission was encouraged to conduct research on the application of nuclear science to agricultural research, and the Institute of Nuclear Agriculture was set up in Mymensingh
- Research on other crops (such as vegetables, fruits, pulses, oilseeds, and wheat) was organized under the Bangladesh Agriculture Research Institute
- Earlier soil research units were regrouped under the Soil Research Institute
- An agricultural university was established in Mymensingh

Since independence, efforts have focused mainly on strengthening the effectiveness and expanding the scope of agricultural research. The first task of the new Bangladesh government in this regard was to organize a research council to coordinate and monitor various institutes and to enhance resources for efficient research.

The creation of the Bangladesh Agricultural Research Council (BARC) in 1973 was a strategic step to enhance efficiency in research management. Initially BARC was conceived as a body to coordinate discrete research institutes under the ministries of agriculture, livestock, fisheries, and forestry; but through a number of legal enactments, particularly one in 1996, BARC has become the cornerstone institution responsible not only for coordination but also for the preparation and implementation of an agricultural research strategy that maintains the administrative autonomy of individual institutes. BARC has developed a master plan for research and human development and unified incentive structures, initiated review processes for various institutes, and introduced a grant mechanism for specific research projects. The names of individual institutes under BARC, their functions, staff strength, and extent of staff attrition are shown in Table 6.2.

The table clearly indicates that research on crops dominates the national agenda, reflecting an early development policy preoccupation with achieving food-grain self-sufficiency and expanding jute exports. The research institutes are generally organized with a central research hub for each institute and a large number of substations located around the country, with the intent of tailoring research to various agroecologies. The implications of the last column in Table 6.2 will become clear when we discuss human resources for research.

NGOs and the Private Sector

Of a total of about 7,000 nongovernmental organizations (NGOs) in the country, about 1,500 are involved in agriculture, providing credit for employment- and income-generating activities and information on agricultural technology. The NGOs do little research but are involved in development programs for livestock, fisheries, sericulture, apiculture, and forestry. These activities are believed to have made significant changes in rural society, particularly in the landless communities.

Bangladesh has virtually no private institutions for agricultural research. To strengthen the incentives for private participation in research, the government enacted legal provisions for patent rights almost a century ago (in 1911), to be followed by trademark protection legislation in 1940 and a copyright act, which came into force in November 2000.[2] Although patents for nonagricultural innovations have been registered (there were 59 applications by residents in 2001, with 21 granted as of May 2003), none have been registered for seeds, crop varieties, plant types, or any other agricultural technologies.

Sources of information on private agricultural research are limited mostly to personal experiences before 1986, when a survey was conducted under a project organized jointly by the University of Minnesota and Rutgers University. The survey reports that there was little private agricultural research undertaken in Bangladesh (Pray 1987), and what there was mostly involved transferring technologies from elsewhere rather than generating new innovations locally. The most effective program was the Bangladesh Tobacco Company's applied research involving adaptive trials of imported Virginia and burley tobacco. Several pesticide companies had small R&D programs, and the largest pump manufacturer did some research on pump designs. Finally, one company was conducting trials on different varieties of vegetables.

Table 6.2 Bangladesh: Description of research institutes, 2001

Institute name	Acronym	Year of inception	Ministerial affiliation	Primary functions	Average number of scientists, 1995–2000	Scientific staff attrition, 1995–2000
Bangladesh Agricultural Research Institute	BARI	1970	Agriculture	Crop research, with the exception of rice, tea, sugarcane, and jute	700	230
Bangladesh Rice Research Institute	BRRI	1970	Agriculture	Rice research	230	58
Bangladesh Jute Research Institute	BJRI	1958	Agriculture	Jute research (various aspects)	200	8
Bangladesh Sugarcane Research Institute	BSRI	1973	Agriculture	Sugarcane breeding	75	9
Bangladesh Tea Research Institute			Commerce	Tea research	36	35
Bangladesh Institute of Nuclear Agriculture	BINA	1972	Atomic Energy Commission	Application of nuclear science to agriculture	107	2
Bangladesh Fisheries Research Institute	BFRI	1984	Fisheries	Fish culture (various aspects)	65	1
Bangladesh Livestock Research Institute	BLRI	1984	Livestock	Cattle and poultry research	35	1
Bangladesh Forest Research			Forest	Forestry (various aspects)	100	27
Soil Resource Development Institute	SRDI	1986	Agriculture	Soil and fertility research and monitoring (various aspects)	454	4

Source: BARC 2001.

Note: Number of scientists excludes research managers.

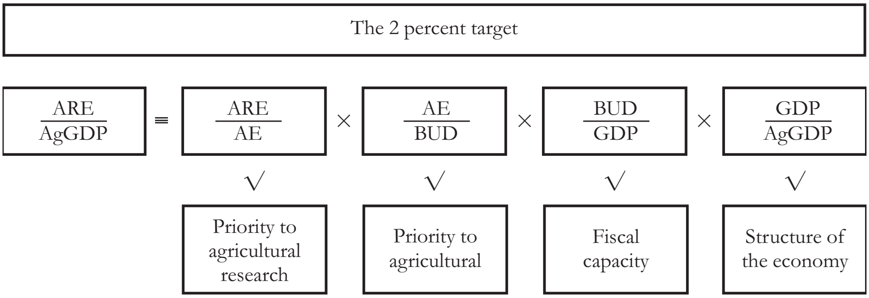
To update the 1986 survey, IFPRI and BARC sought information on private-sector agricultural R&D during September–October 2001 and February–March 2002. It appears that the scope and intensity of private-sector R&D has expanded somewhat. However, as in the mid-1980s, most of this private activity involves the importation of new technology rather than local innovation. Pesticide companies, poultry producers, fish farmers, and certain NGOs are importing a host of technologies, ranging from seeds to plant-growth regulators. Some of these importers are making efforts to fit these agricultural techniques into domestic production practices. A couple of large commercial poultry farms, for example, are importing chicks from the Netherlands, along with complementary modern technologies for controlling disease on their farms. A number of NGOs are also involved in small-scale adaptive research and dissemination of modern agricultural technology. In addition, food processing enterprises, which are increasing rapidly both in number and volume of business, are involved in R&D pertaining to packaging materials, quality of processed products, and storability of products, particularly those meant for the export market.

Even though private investors are gradually coming forward to invest in agricultural R&D, the total effort of the private sector is still small. Why is this the case? The Minnesota–Rutgers study speculated that the small size of the modern agricultural input and processing sector and government policies are responsible. The binding constraints, the report argues, are underdeveloped agriculture and government intervention in industries. While few would disagree with this broad conclusion, there are other reasons too. Risk is a formidable constraint. Other barriers include weak demand for new innovations from the large number of small and semisubsistence farmers, perceived competition from government research, and the demise of big business conglomerates.

Public Resources for Agricultural Research

To what extent should public resources be invested in agricultural research? This is a complex question with no straightforward answer, not least because resource-allocation decisions are ultimately made by politicians, not economists. Beyond the equi-marginal, benefit–cost investment principle espoused by economists (see, for example, Alston, Norton, and Pardey 1998), various rules of thumb have been used to guide the allocation of funds to agricultural R&D. The 1974 UN World Food Conference suggested that developing countries should aim for a 1985 target of allocating 0.5 percent of AgGDP to agricultural research (United Nations 1974, p. 97). The World Bank (1981, p. 8), in a widely quoted statement, asserted that a "desirable [agricultural research] investment target . . . would be an annual expen-

Figure 6.1 Bangladesh: The agricultural research-intensity ratio target



Notes: ARE indicates agricultural research expenditures, AgGDP agricultural gross domestic product, AE all agricultural expenditures, and BUD the government budget.

diture (recurrent plus capital) equivalent to about 2 percent of agricultural gross domestic product." Imperfect as this ratio may be, it serves as a reference for judging the adequacy of public resources allocated to agricultural research. However, as Pardey, Kang, and Elliott (1989) pointed out, the ratio of agricultural research expenditure to agricultural GDP is best seen within the broader context of the process of public-resource allocation, as reflected in the identity shown in Figure 6.1.

The identity expresses the ratio of agricultural research expenditure (ARE) to agricultural GDP (AgGDP) as the product of ratios. The first ratio (ARE/AE) is the share of agricultural research expenditure in all agricultural expenditures. It may be taken as the priority given to agricultural research within the agricultural strategy. The second ratio (AE/BUD) is the share of agricultural expenditures in the government budget. We call this the "priority to agriculture." The third ratio (BUD/GDP) is government expenditure's share of gross domestic product. It may alternatively be considered as the "fiscal effort" (which reflects the will of a government to take a role in the economy), the "fiscal burden" (which reflects the weight of the public sector on the economy), or the "fiscal capacity" (which reflects the existence of high-value, easily taxed sectors). The final ratio (GDP/AgGDP) is the inverse of agriculture's share of gross domestic product.[3]

Following the above framework, Bangladesh's public expenditures are analyzed at three stages. First, aggregate public expenditures are examined to indicate the size of the government in relation to the size of the economy (BUD/GDP). Second, the sectoral analysis demonstrates the priority given to agriculture relative to other sectors. Finally, the intrasectoral allocations are examined to show the priority of agricultural research in the budget for agriculture.

Aggregate Public Expenditure

The annual budget has two components: annual development program (ADP) and annual current budget. The current budget is also termed the "revenue budget." The ADP includes project-by-project allocations for the budget year and estimates of expenditures for the previous year for all ministries and agencies. It is the annual phase of implementation of development projects under a five-year plan. Most, but not all, the projects included in the five-year plan are accommodated in the ADP. These projects are supposed to be processed and approved through an interministerial committee organized under the direction of the Planning Commission before they are accommodated in the ADP. ADP can be considered in some measure akin to the public-sector investment budget.

The current budget is meant for general administration, security, and regular functions of the government. The demands for the current budget are first matched against revenue collection, and any surplus from this balancing of current budget and revenue collection (tax and nontax revenue) is available for financing the ADP. The combined demands for ADP and the current budget, when balanced against the total revenue collection, provide an initial indication of the magnitude of deficit financing. Macroeconomic considerations, on the other hand, tend to limit the extent of deficit financing from domestic sources. The deficit is therefore partly financed by foreign aid in the form of commodity grants and project aid, and partly by domestic borrowing from the banking system and nonbank public sources. Foreign financing covered an average of 85 percent of total deficits from 1985 through 1995 (World Bank, Bangladesh Country Operations Division 1996). Currently, about 52 percent of the deficit is financed from foreign sources. Final budget figures result from harmonization among all these fiscal factors. The overall fiscal deficit was about 7.5 percent of GDP in the mid-1980s and declined to about 5.6 percent in the second half of the 1990s. This change reflects reform in the tax structure, improvement in tax collection, and increased reliance on domestic borrowing.

The budget statistics for the years 1976 through 2004 are presented in Table 6.3. The absolute magnitude of annual average total public expenditures, in nominal taka terms, has increased from about Tk. 35 billion in the first period to about Tk. 409 billion in the fifth period—an increase of about 12-fold over 24 years. In terms of dollar-equivalent expenditure, the increase is only about 3-fold, the difference reflecting the effects of depreciation in the country's rate of currency exchange and inflation. In terms of expenditure at 1996 constant prices, the increase is equivalent to about 4.5 percent per annum compared with a rate of growth of GDP of about 5.0 percent per annum. Current expenditure has increased faster than development expenditure: the ratio of development expenditure to total expenditure fell

Table 6.3 Bangladesh: Trends in annual average public expenditure, 1976–2004

Indicators	1976–81	1984–90	1991–95	1995–2000	2001–04
Total expenditure					
Million taka	35,200.0	97,478.6	190,232.2	278,678.0	408,810.0
Million U.S. dollars	2,186.0	3,157.3	4,844.6	6,245.4	6,929.0
Development expenditure					
Million taka	18,135.5	47,110.0	94,892.0	129,650.0	145,786.0
Million U.S. dollars	1,137.3	1,535.1	2,414.8	2,911.6	2,471.0
Current expenditure					
Million taka	13,518.3	50,368.6	95,340.2	149,028.0	263,021.0
Million U.S. dollars	839.3	1,622.2	2,429.8	3,333.8	4,458.0
Ratio (percent)					
Development expenditure/total expenditure	51.5	48.3	49.9	46.5	35.7
Total expenditure/GDP	16.3	16.0	13.6	14.5	13.5
Development expenditure/GDP	10.1	7.9	6.4	8.3	4.8
Current expenditure/GDP	6.2	8.1	7.2	7.7	8.7
Project aid/development expenditure	32.3	56.1	47.1	41.4	37.0

Sources: For expenditures, BBS, various years; for GDP and exchange rates, World Bank 2001 and Ahmed 2002. The 2004 statistics are from the authors compilation of data obtained in connection with a public expenditure review in preparation for the World Bank (Ahmed and Mudahar 2006 forthcoming).

Note: Expenditures and GDP are in current prices.

from 51.5 percent in the first period to 35.7 percent in the fifth period. The increased cost of democratic institutions and defense expenditures are largely responsible for the faster increase in current expenditure.

The ratio of public expenditures to GDP is, perhaps, more meaningful than absolute magnitudes. The ratio of total public expenditure to GDP, an indicator of the size of the government, was 16 percent in the first period, gradually declining to about 14 percent of GDP by the third period and stabilizing at that level thereafter. This modest decrease in the size of the public budget relative to GDP was a consequence of emphasizing a market-oriented strategy of development through reforms. The ratio of development expenditure to GDP declined faster than the ratio of total (development plus current) expenditure to GDP, while the ratio of current expenditure to GDP in fact increased slightly. An interesting aspect of public expenditure, particularly the development expenditure, is the extent of foreign project aid in financing the development budget. In the second half of the 1970s, only about 32 percent of developmental expenditures were financed through project aid. This proportion peaked at 56 percent during the second half of the 1980s. Thereafter, the proportion of project aid dropped to 47 percent in the first half of the 1990s and to 37 percent in the period 2001–04. The low level of project aid during the late 1970s is understandable: foreign aid flows into Bangladesh were limited after the war of independence disrupted relationships with donors. However, the decline in project aid during the 1990s, from its peak in the second half of the 1980s, is not readily understandable. Ostensibly there are at least three reasons for this. First, it is natural to surmise that the proportion of project aid declined during the 1990s, given a worldwide contraction in the supply of foreign aid. However, this was not the case for Bangladesh. Aid commitments from donors continued to increase during this period, and the accumulated foreign aid in the pipeline was $5.7 billion as of June 2000. It is the increasing gap between commitment and utilization that caused the decline in the proportions of project aid during the 1990s. A second possibility, namely that the increasing shift of donor assistance to NGOs caused shortfalls in public-sector project aid, is also not an adequate explanation, as NGOs receive only a small share (about 15 percent) of overall project aid to Bangladesh. A third reason seems the most plausible: namely that a sharply deteriorating trend in governance, buttressed by aid conditionalities, caused a fall in the proportion of foreign-aid dispersals.

Sectoral Distribution of Public Expenditure

The definition of sectors is important when inferring priorities from the sectoral distribution of expenditures. The agricultural sector in the Bangladesh economy is traditionally defined to include crop production, marketing of food (including public food marketing), livestock, fisheries, and forestry production. Economists have tended to include rural institutions and rural infrastructures, as well as flood control and large irrigation development activities, as components of agriculture. This practice gives rise to two definitions of the agricultural sector, one somewhat narrower than the other: the first includes crops, food marketing, livestock, fisheries, and forestry, while the second also includes rural institutions and infrastructure, and water control and development. We present sectoral distributions in which agriculture, rural development and institutions, and flood control and water resources are shown separately.

The sectoral distributions of public expenditure are shown separately for ADP and current expenditures. Typically, limitations in detailed, disaggregated data for the current budget do not allow a straightforward addition of the two budgets at sectoral levels. However, for the agricultural sector, we made a concerted effort to collect detailed, disaggregated data, including data for the current budget, that we present in the intrasectoral analysis of agriculture.

The sectoral shares in the ADP are shown in Table 6.4. The agricultural sector, as traditionally defined, has been losing ground in the development budget: from a 14 percent share during 1976–81, it gradually declined to 4.0 percent during 2001–04. However, using the broader definition of the agricultural sector, inclusive of

Table 6.4 Bangladesh: Average sectoral shares of total annual development program, 1976–2004

Indicator	1976–81	1984–90	1991–95	1995–2000	2001–04
Agriculture	14.0	7.0	5.9	4.7	4.0
Rural development and institutions	3.7	3.4	6.4	8.7	12.3
Flood control and water resources	12.9	12.3	9.1	7.2	4.5
Industry	15.5	8.3	1.4	1.1	2.3
Power	10.7	15.2	12.4	11.0	15.2
Natural resources	3.6	5.2	4.4	3.9	4.2
Transport	15.4	9.4	16.9	18.5	17.4
Communication	3.0	1.9	3.6	2.7	3.5
Physical planning and housing	6.3	3.6	4.7	5.4	6.3
Education and training	4.2	4.9	10.5	12.9	13.5
Health, population control, and family planning	5.8	6.2	8.0	5.9	7.7
Social welfare, women's affairs, and youth development	0.7	0.5	0.9	1.4	1.2
Other	4.2	22.0	15.9	16.7	7.9

Sources: Compiled by the authors from unpublished Government of Bangladesh budget documents and Ahmed 2002. The 2004 statistics are from the authors' compilation of data obtained in connection with a public expenditure review in preparation for the World Bank (Ahmed and Mudahar 2006 forthcoming).

rural institutions and water development, the decline has been less pronounced: an average share of 30.6 percent in 1976–81, declining to 20.8 percent in 2001–04. Notably, the share of ADP spending on rural development and institutions increased from 3.7 percent in the first period to 12.3 percent in the final period.

The share of industry shrank drastically, from 15.5 percent in the first period to only 2.3 percent in the final period. The education share tripled, the social welfare share doubled, and the transport-sector share increased only marginally between the first and the fifth periods. The shares of ADP spending directed toward power increased substantially, and those for communication, natural resources, and health changed only modestly.

These changing spending priorities among sectors are broadly consistent with recent thinking in development economics that emphasizes the important roles of improvements in human resources and increasingly market-oriented development strategies in accelerating growth. In Bangladesh, this thinking on development strategy was enacted through structural reforms that directly affected public spending priorities. Interestingly, spending on health, population control, and communications do not command the priority accorded to education.

Another significant dimension of the distribution of public expenditures among sectors is the extent of project aid in various sectors, perhaps reflecting, in part, the donors' perception of priorities among sectors. The sectoral composition of project aid is shown in Table 6.5. For the agricultural sector, narrowly defined,

Table 6.5 Bangladesh: Project aid as share of annual development program, by sector, 1976–2004

Indicator	1976–81	1984–90	1991–95	1995–2000	2001–04
Agriculture	20.0	52.0	56.2	51.7	43.9
Rural development and institutions	26.0	83.7	62.4	49.2	30.5
Flood control and water resource	23.4	61.0	47.5	55.2	27.5
Industry	53.4	60.8	20.1	22.8	29.0
Power	40.0	74.6	47.8	33.3	43.9
Natural resources	37.2	55.4	58.2	49.4	37.4
Transport	37.2	55.4	58.2	49.4	57.6
Communication	24.0	47.7	31.4	27.3	35.2
Physical planning and housing	24.1	43.2	40.4	39.0	41.4
Education and training	14.0	60.1	47.2	29.7	24.4
Health, population control, and family planning	34.9	61.2	60.0	63.0	62.6
Social welfare, women's affairs, and youth development	12.9	31.4	30.1	24.4	23.1
Other	17.2	29.6	25.4	25.2	24.2

Sources: Compiled by the authors from unpublished Government of Bangladesh budget documents and Ahmed 2002. The 2004 statistics are from the authors' compilation of data obtained in connection with a public expenditure review in preparation for the World Bank (Ahmed and Mudahar 2006 forthcoming).

along with natural resources, power, health, and transport, the average proportions of project aid are higher than the national average for all sectors. From 1976 through 1981, the industry and power sectors received disproportionately large amounts of project aid, but these have fallen drastically, particularly aid for industry.

The sectoral shares in current expenditure are shown in Table 6.6. Unfortunately, current expenditures are not available in sufficiently disaggregated form to reveal longer-run sectoral trends that correspond to the ADP series just discussed. Despite these shortcomings, we can draw some conclusions. The current budget does not exhibit the marked changes in sectoral shares evident in the development budget: in 1990–94, education took the largest share of the current budget, followed closely by defense, then by general administration and debt servicing. Police and justice together accounted for 7.2 percent of the current budget. Given the country's current difficulties with law and order and governance, this share is arguably too low.

Subsidies account for about 5 to 6 percent of the current budget. The share going to food subsidies has declined but still accounts for about 3 percent of the current budget. The subsidy on public enterprises has increased, and it accounted for 2.6 percent of the current budget in 1990–94.

The share of agriculture in the current budget is quite low—barely 4 percent. Given the role of agriculture in the economy and its importance in the development

Table 6.6 Bangladesh: Average sectoral expenditure shares in current budget, 1984–90 and 1990–94

Items of expenditure	1984–90	1990–94
General administration	12.7	14.7
Justice and police	7.4	7.2
Defense	18.4	17.3
Scientific departments	0.5	0.6
Education	16.9	18.4
Health and family planning	5.4	6.0
Social welfare	9.8	7.7
Agriculture	3.8	4.1
Manufacturing and construction	0.6	0.4
Transport and communication	1.7	2.2
Other	1.0	1.0
Debt service	11.5	12.2
Food subsidy	6.5	3.1
Other subsidy	2.0	2.6
Contingency	2.7	2.5

Source: Calculated by authors from World Bank, Bangladesh Country Operations Division 1996.

Note: "General administration" primarily reflects a subsidy to compensate losses to public enterprises. This is not a true picture of the loss because the debt of public enterprises to nationalized commercial banks is not included. Recent data on current budget are available in a different form, that is, by administration division rather than a functional form as in this table. The conversion from administrative to functional forms for all sectors warrants further research.

budget, this small share perhaps reflects the low priority given to agriculture in allocation of the nation's own revenues.

Often in Bangladesh, when a project in the ADP is completed, if its operation thereafter is to be maintained, then the operation must be financed from the current budget. Given that the agriculture sector accounts for such a small share of the current budget, one wonders how agricultural development activities initiated under the development budget are sustained.

Intrasectoral Allocations in Agriculture and Agricultural Research

The analysis of intrasectoral allocations that follows is based on the narrow definition of the agricultural sector and is limited to development expenditures only (Table 6.7). The crop subsector continues to dominate, drawing 69 percent of developmental expenditures in agriculture between 1976 and 1981, a share that declined to 44 percent in the period 2001 to 2004. The food marketing subsector had a 13 percent share in the first period, dropping to 4.4 percent in the final

Table 6.7 Bangladesh: Average subsectoral expenditures in total agricultural development expenditure, 1976–2004

Subsectors	1976–81	1984–90	1991–95	1995–2000	2001–04
Crops					
Million taka	1,566.6	1,652.1	2,531.5	3,123.0	4,527.5
Percentage	68.6	50.5	45.8	51.5	43.9
Forestry					
Million taka	161.1	443.8	897.0	1,005.7	1,700.0
Percentage	7.1	13.6	16.3	16.6	16.5
Food marketing					
Million taka	294.5	266.5	397.5	355.3	452.5
Percentage	12.9	8.1	7.2	5.8	4.4
Fisheries					
Million taka	179.1	522.2	935.1	703.0	1,330.0
Percentage	7.8	16.0	16.9	11.7	12.9
Livestock					
Million taka	82.0	385.9	761.5	871.9	2,300.0
Percentage	3.6	11.8	13.8	14.4	22.3
Total agriculture (narrow)					
Million taka	2,283.2	3,270.4	5,522.6	6,058.8	1,0310.0
Percentage	100.0	100.0	100.0	100.0	100.0

Sources: Calculated by the authors from data in unpublished Government of Bangladesh budget documents and Ahmed 2002. The 2004 statistics are from the authors' compilation from data obtained in connection with a public expenditure review in preparation for the World Bank (Ahmed and Mudahar 2006 forthcoming).

period.[4] This decrease reflects reforms in the public marketing of food. The share of agricultural spending directed toward fisheries increased from 8 percent in 1976–81 to about 13 percent by the early 2000s. Similarly, the forestry share increased from 7 to about 17 percent, and the livestock share from about 3 to about 22 percent. These changes in the subsectoral shares in agriculture broadly reflect shifting agricultural policy, emphasizing diversification from crop to noncrop agricultural products as sources of agricultural growth.

Agricultural Research

Table 6.8 shows the proportion of agricultural expenditures devoted to agricultural research. It appears that only 8.6 percent of agricultural development expenditures were spent on agricultural research from 1976 through 1981, increasing to 12.5 percent in the period 2001–04.[5] The total agricultural development expenditure directed to R&D, including rural institutions and water development (that is, using the broad agriculture definition), was just 3.9 percent during the period 1976–81, dropping to 2.9 percent in the period 2001–04. Adding current expenditures to the development expenditures for agricultural research provides a more

Table 6.8 Bangladesh: Average public expenditure on agricultural research, 1976–2004

Indicator	1976–81	1984–90	1991–95	1995–2000	2001–04
Expenditure (million taka)					
Research development expenditures	195.4	618.6	605.0	968.1	978.0
Research current expenditures	50.6	198.0	254.7	307.6	527.0
Total research expenditures	246.0	816.6	859.7	1,275.7	1,505.0
Research development expenditures as percentage of total development expenditures in agriculture (narrow)	8.6	18.9	11.0	15.8	12.5
Research development expenditures as percentage of total development expenditures in agriculture (broad)	3.9	5.8	3.0	3.6	2.9
Total research expenditures as percentage of agricultural gross domestic product	0.35	0.34	0.27	0.25	0.24
Project aid as percentage of research development expenditures	42.9	55.9	38.2	48.2	38.4

Sources: Calculated from data in unpublished Government of Bangladesh budget documents and information collected from BARC on individual research institutes. The statistics for 2001–04 are from authors' compilation of data obtained in connection with a public expenditure review in preparation for the World Bank (Ahmed and Mudahar 2006 forthcoming).

complete picture of public expenditures. When this total is expressed as a proportion of agricultural GDP, it appears that Bangladesh devotes only a tiny proportion of its resources to agricultural research—0.35 percent during the period 1976–81 and 0.24 percent for the period 2001–04. This figure is well below the 2 percent target considered appropriate for research, and half the 1995 developing-country average (0.62 percent) reported by Pardey and Beintema (2001).

The data show that the share of project aid in total agricultural research expenditures has been volatile. It was 43 percent in the period 1976–81, increasing to 56 percent in the period 1984–90, declining to 38 percent during the first half of the 1990s, and rebounding to 48 percent during the second half of that decade. Compared with the proportions of project aid in total agricultural development expenditures (Table 6.5), it appears that research enjoyed a higher share of project aid during the first two periods but lost ground during the subsequent two periods. The decrease in total research expenditures, combined with a dwindling proportion of foreign aid in the development funds directed to agricultural R&D, could represent a cause for serious concern, especially as Bangladesh has been vigorously championing poverty reduction and improving the competitive strength of its agricultural sector in an increasingly globalized market.

Table 6.9 shows how research expenditures are distributed among various commodity-oriented research institutes. Crop research institutes command a larger

Table 6.9 Bangladesh: Subsectoral shares in expenditures on agricultural research, 1976–2004

Subsector	1976–81	1984–90	1991–95	1995–2000	2001–04
Annual development program (percent)					
Crops	84.65	77.82	84.01	79.57	78.5
Forestry	3.89	4.95	3.34	5.78	7.44
Fisheries	10.85	11.07	7.55	7.77	8.25
Livestock	0.61	6.16	5.10	6.88	5.81
Total	100.00	100.00	100.00	100.00	100.00
Current budget (percent)					
Crops	90.52	85.15	87.67	87.91	85.12
Forestry	4.15	4.14	2.20	3.32	3.50
Fisheries	4.74	7.93	7.34	5.23	7.66
Livestock	0.59	2.78	2.79	3.54	3.72
Total	100.00	100.00	100.00	100.00	100.00
Total research budget (percent)					
Crops	85.80	79.60	85.00	81.60	80.80
Forestry	4.00	4.70	3.10	5.20	6.00
Fisheries	9.60	10.30	7.50	7.20	8.10
Livestock	0.60	5.40	4.40	6.00	5.10
Total	100.00	100.00	100.00	100.00	100.00

Sources: Calculated by authors from unpublished Government of Bangladesh budget documents and information collected from BARC on individual research institutes. The statistics for 2001–04 are from the authors' compilation of data obtained in connection with a public expenditure review, 2005, in preparation for the World Bank (Ahmed and Mudahar 2006 forthcoming).

share of both development and current budgets than noncrop institutes, although the crop share has declined a little since 1976. Fisheries research comes next, with about 9 percent of the total research budget. It reflects a slightly smaller share of the agricultural development budget in 2001–04 than in 1976–81, and a modest increase in the current budget share. Forestry commands 6 percent of total agricultural R&D spending, with a modestly increasing share of the development budget but a declining share of the current budget. Livestock research accounts for the smallest share of the agricultural research budget, although this share has increased markedly since 1976 in both the development and current budgets.

By the very nature of agricultural R&D there are long lags between investment and reaping the returns on that investment, and therefore some stability is needed in the flow of funds to research. Unfortunately, in the case of Bangladesh the revenue flows to agricultural research are not only relatively small but also highly unstable (Table 6.10). The yearly fluctuations in agricultural research expenditure vary from –49.88 to 73.36 percent, and they are significantly larger than fluctuations in other fiscal variables, such as ADP, current expenditures, and project aid. Nominal expenditures in agricultural research fell in 6 of the 21 years examined; other fiscal factors declined in only 2 or 3 of the 21 years.[6]

Table 6.10 Bangladesh: Range of annual fluctuation in selected fiscal variables, 1978–99

Fiscal variable	Range of fluctuation (percent)	Number of years with negative fluctuation
Development budget (ADP)	–2.41 to 33.2	2
Current budget	6.11 to 23.93	0
Total project aid	–5.30 to 35.19	3
Development budget for agriculture	–18.21 to 30.63	2
Agricultural research budget	–49.88 to 73.36	6

Sources: Calculated from data in unpublished Government of Bangladesh budget documents and information collected from BARC.

Human Resources for Agricultural Research

Innovation processes are critically reliant on access to appropriately trained and creative scientists and technicians. There are at least four dimensions to the human resource requirements of agricultural research: staff strength, balanced composition, training, and incentives.

Number of Scientists with Required Disciplinary Knowledge

Research managers, senior scientists, and junior research scientists constitute the largest group of research staff in national research institutes. Table 6.2 gives a 2001 snapshot of the scientific staff strength in various agricultural research institutes. It shows that 2,185 research managers and scientists were employed in the main agricultural research organizations of Bangladesh. About 12 percent held Ph.D.s, 75 percent M.Sc.s, and 13 percent B.Sc.s. Generally, the most senior scientists are engaged in research management; these constitute about 9 percent of the scientists employed.

Typically, an agricultural research institute is headed by a director or director general. Under the head, there are chief scientific officers (CSOs), principal scientific officers (PSOs), senior scientific officers (SSOs), and scientific officers (SOs). In addition, there are technicians to support the scientists in specific scientific operations. The head and CSOs jointly constitute the group of research managers. The PSOs, SSOs, and SOs conduct research. The PSO is the leader, the SSOs carry out the research, and the SOs provide support to the senior investigators. Based on international practices and local realities, a report on human resource development in agricultural research recommended a ratio of 1:2:4 among the positions of PSO, SSO, and SO as optimal for the agricultural research system in Bangladesh (Hasanuzzaman 2000).

However, because of a large-scale migration of scientists to jobs abroad, primarily during the years 1995 to 2000, not only the absolute levels but also the optimal mix of senior and junior scientists has been adversely affected. The extent of this attrition for the period 1995–2000 is shown in Table 6.2. The loss of scientists from the Bangladesh Agricultural Research Institute (BARI), the Bangladesh Rice Research Institute (BRRI), BARC, and the Forestry Research Institute (FRI) has been serious; about a quarter to half of the scientists working in these institutes have left their jobs, mostly to pursue opportunities abroad. Because the better-qualified and skilled scientists are more likely to get jobs abroad than the ones with lesser qualifications, these departures imply a loss not only in number but also in quality. Research managers feel that the migration of scientists has created a vacuum of crisis proportions in agricultural research, and it warrants a commensurate effort to minimize the adverse impact of this brain drain.

Unfortunately, it is difficult to remedy a brain drain, especially in an era of global integration. To minimize the negative effects, efforts to develop capacity will have to be expanded, and incentives will have to be enhanced so that at least some scientists find sufficient reason to stay home.

Motivation and Incentives

Knowledge, skill, and experience are necessary but not sufficient to guarantee a productive outcome from research. The dedication and motivation of scientists are also important, and these elements are especially sensitive to the incentive structures in research institutions. Yet it is virtually impossible to offer an incentives structure to a particular branch of the government (for example, agricultural research) that is fundamentally different from that in other branches of government. Nevertheless, small improvements are possible, and a combination of some of these may be sufficient to better motivate agricultural scientists.

The salary structure of scientists ranges from about $113 to $345 per month, depending on rank. This structure cannot be changed in isolation from the government system as a whole. Some fringe benefits, such as special allowances, could be increased, but only with great difficulty. Therefore, the scope of any special change in salary and benefits exclusively for scientists remains extremely slim. Improvements in promotion procedures and special recognition, together with enhancement of the social image of scientists, could conceivably improve motivation among scientists.

Currently, even scientists with advanced degrees from Western universities are typically employed in the same position for 8 to 12 years before promotion. This peculiar situation has developed because of the small number of approved senior positions in most research institutes. The number of approved positions was determined when the various institutes were first established, and changing it is difficult within Bangladesh's public-service rules and tradition. However, with the increasing autonomy of research institutes, granting promotion based on experience and performance, regardless of the number of approved positions, may become possible.

Social image is important in cultivating a sense of pride among scientists, particularly in societies like that of Bangladesh, whose government officers are classified into explicit classes. Not too long ago, graduates in agricultural science were held in much lower esteem than graduates in medicine or engineering. Although these attitudes and practices persist, they are undesirable and sustain an artificial and demeaning culture in public service.

Impact of Agricultural Research

Recently an opportunity opened up for a review of public expenditures in Bangladesh for a multilateral donor. In the course of this assignment, a strong case for increasing resources for agricultural research was presented. The policymakers and top professional advisers responded by contending that the success in rice production resulted from irrigation development and fertilizer policy, and the complementary inputs for high-yielding varieties (HYV) of rice. They apparently did not understand the contribution of research in the development of HYV. Increased use of fertilizers and irrigation were tried in the 1960s with little success; production increased only in the 1980s and 1990s, when modern HYVs became part of the package of complementary inputs. When this contrast was pointed out to policymakers, they seemed to be lost for a moment; strong disagreement turned to skepticism. The dialogue ended with a vague agreement to revisit this issue.

This episode is indicative of the challenge in measuring research benefits and communicating the results to policymakers. Empirical studies on returns from research are numerous. Estimated rates of return vary widely but are generally high (see Alston et al. 2000 for an excellent analytical review). It is the measurement of benefits that is the source of most confusion. The concept of total factor productivity (TFP) is useful for measuring aggregate research benefits (see Solow 1957 and Griliches 1963). The fact that real costs of complementary inputs are netted out from gross revenue in the measurement of TFP makes the residual a suitable measure of technology's contribution, particularly when the effect of any plausible economies of scale is accounted for. Nevertheless, the approach is not free of controversies (see Fagerberg 1994 and Felipe 1999).

The contribution of research to growth in rice production in Bangladesh can be measured through the estimates of TFP. Rice production represents half of agriculture, and rice research has received the highest priority. About 45 modern varieties have been released that cover 70 percent of the country's rice area. Rice yield

Table 6.11 Bangladesh: Annual growth rates in rice revenue, input costs, and total factor productivity (TFP), 1975–76 to 1997–98

	1975–76 to 1986–87	1987–88 to 1997–98	1975–76 to 1997–98
Based on current prices			
Output	10.71	3.72	7.22
Input	9.52	2.86	6.19
TFP	1.19	0.86	1.03
Based on constant prices			
Output	2.91	4.02	3.51
Input	2.12	2.65	2.41
TFP	0.79	1.37	1.10

Source: Ahmed 2001.

Note: Constant prices are for 1981–82.

has doubled, contributing to the doubling of rice production during the past two decades (Shahabuddin and Rahman 1998).

Estimates of the average rate of growth in output, input, and TFP are presented in Table 6.11. (For details on the method of calculation, see Ahmed 2001.) Values for individual years vary widely because of floods, droughts, and other natural factors, so averages over a number of years are shown—for 1975–76 to 1986–87, for 1987–88 to 1997–98, and for the entire period 1975–76 to 1997–98. Two sets of measures are provided, based on nominal and real (1981–82) prices.

In spite of the comparatively small investments in agricultural research documented above, the technological progress in agriculture, as measured by total factor productivity growth in rice, has been solid. The growth rate in TFP in rice production was slightly higher than 1 percent per annum in the period 1975–76 through 1997–98. Comparing growth rates in TFP estimated using nominal and real prices, it appears that over the entire period, the difference between the two narrows, but in the first and second decades, using different prices can influence the perspective on TFP growth. Prices do matter, mostly in the shorter rather than the longer run, in the measurement of TFP.

How does this growth in TFP compare with similar agricultural products in India? Evenson, Pray, and Rosegrant (1999), who estimated the TFP for crops in eastern India (West Bengal, Orissa, and Behar), found that the annual growth rate in crop TFP was 0.75 percent during the period 1956–87. The Bangladesh estimate considers only rice, while the Indian estimate includes rice and other crops, and so the two estimates are not strictly comparable. However, since rice is the largest crop in eastern India as well as in Bangladesh, such a comparison is still useful.

In the rice economy of Bangladesh, the real price of rice declined over the period 1975–76 to 1997–98; the decline was sharper in the second decade than in the first (Ahmed 2001). But the growth in production of rice, in the face of this declining real price, has been spectacularly sustained. This growth has been possible because of the sustained improvement in TFP. Rice prices in Bangladesh have come very close to world prices. Therefore, for further increases in production, productivity will play a more strategic role than prices.

Rice research has indeed paid off in Bangladesh. The increase of 1 percent annually in TFP in rice production implies an annual contribution of about 170,000 metric tons of rice, valued at about $42.5 million (equivalent to Tk. 1.913 billion at the official exchange rate). Annual public expenditure on rice development, using total expenditures of the BRRI and 50 percent of total expenditures on agricultural extension services, averaged Tk. 118.9 million from 1990 through 1997. Based on these figures, a crude estimate of the benefit–cost ratio of rice research is 16:1, an extremely high rate of return.

Concluding Observations

Bangladesh has a rich history of agricultural research. But building on this historical foundation has been slow, as the resources available for research have remained very limited. Only about 4 percent of total public developmental expenditure in agriculture, which is equivalent to about 0.25 percent of agricultural GDP, is allocated to agricultural research. Because of the legacy of strategic research institutions, the achievements of agricultural research have indeed been remarkable. Total factor productivity in rice, a major crop example, has grown, enabling rice production to double even though the real price of rice has fallen sharply and the area under rice has declined slightly. About 70 percent of rice area is currently planted with high-yielding varieties.

The forces of globalization have brought a number of new challenges to agricultural research in Bangladesh. The first is the ability of agricultural research to contribute to the low-cost supply of agricultural products in intensely competitive world markets. Unfettered competition in world markets offers a comparative advantage to countries with superior research skills and institutions to support their agricultural sectors, not least because nonagricultural sectors can rely on imported technology with greater ease than agriculture can. For example, imported biotechnologies often require some adaptation, and local testing and screening, at least, before release to farmers.

The second challenge facing agricultural R&D in Bangladesh is to meet the needs of agricultural diversification. Mobilizing the resources required for research on livestock, fisheries, forestry, and high-value crops, particularly research focusing on quality improvement, must occur faster. Because the proportion of scientists with advanced degrees in noncrop branches of agricultural research is very low, developing the personnel to address these areas of research must become a high priority (Hasanuzzaman 2000).

The third challenge relates to opportunities presented by scientific developments in biotechnology. As the human-health and environmental concerns over biotechnology are adequately addressed, this relatively new branch of agricultural research is destined to cause a sea change in agricultural markets around the globe. Bangladesh has taken some initial steps to develop research capabilities in biotechnology (BARC 2001). Initiatives under the Ministry of Science and Technology include the organization of a biotechnology research institute in Bangladesh.

The systemic problem of inadequate and unstable allocation of public resources for agricultural research has been a common theme in national research evaluation documents (BANSDOC 1997). Discussions with policymakers suggest that resource availability is not perceived as a problem; resource utilization is considered the critical constraint. Scientists, on the other hand, complain about meager and uncertain resource flows, as well as the slow disbursement of funds, as the real constraints. The basic problem is rooted in institutional deficiencies.

The financing mechanism for agricultural research has to be extricated from the current budgetary process, perhaps by establishing some sort of autonomous foundation or trust fund to be administered by a body like BARC. The fund will depend primarily on public resources; therefore budgetary allocations to agricultural research will have to be included in the annual budget. Such a funding mechanism will enable scientists to pursue research activities according to a long-term research plan, avoiding the vicissitudes of annual budgetary allocations and cumbersome financial approvals required by current mechanisms.

The problems of sustaining human resource development in agriculture in general, and the situation arising from outmigration of scientists in particular, call for thoughtful evaluation and corrective measures. It is extremely difficult to stop migration by regulation. While internal improvements in incentives may reduce the outflow, it is doubtful that they can stop it. Therefore, a strong program for training and education of scientists should be undertaken, so that the vacuum can be filled quickly, with the least possible damaging effects on research activities.

Historically, agricultural research institutions have witnessed moments of enormous frustration followed by bold measures of institutional strengthening. Perhaps the current deteriorating situation in agricultural research will herald another resurgence. This time around, perhaps the resurgence will be sustained enough to render the long-run future of agricultural R&D less uncertain.

Notes

1.The subsectoral shares in agricultural GDP for 1972–75 show that the crop subsector accounted for 70 percent, fisheries 11 percent, livestock 10 percent, and forestry 9 percent. Over the past 20 years, the share of the crop subsector fell from 78 percent to 52 percent, while the share of noncrop subsectors increased from 30 percent to 43 percent by 2003/4.

2. Bangladesh has been a signatory to the Trade Related Aspects of Intellectual Property (TRIPs) agreement since January 1995, and to the World Intellectual Property Organization (WIPO) Convention since May 1985, but has yet to join the Patent Cooperation Treaty administered by that organization. The Bangladesh Patent Office operates out of the Ministry of Industries.

3. Pardey, Kang, and Elliott (1989) provided evidence on the political-economy aspects of agricultural R&D using the same sets of ratios as a basis for comparison among countries. In addition to conventional agricultural research-intensity ratios, they developed measures of a public agricultural-expenditure ratio (government expenditure on agriculture relative to AgGDP) and a relative research-expenditure ratio (public agricultural-research expenditure relative to government expenditure on agriculture).

4. In addition to food marketing, there are significant elements of input marketing and service provision in other subsectors; therefore, the share of all types of marketing in the agricultural sector could be as high as 40 to 45 percent (see World Bank, Bangladesh Country Operations Division 1996).

5. Expenditures by BARC, BARI, BRRI, BJRI, BINA, BSRI, BLRI, BFRI, BTRI, BFORI, and SRDI were included as research expenditures. Information on both development and current expenditures was collected from these institutes to supplement statistics in budget documents.

6. We attempted to use statistical regression methods to estimate the extent of the influence of various fiscal variables on the instability of research expenditures. The results were statistically poor, but the variability in project aid for research was found to be a significant cause of variability in research expenditures.

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Chapter 7

India: The Funding and Organization of Agricultural R&D—Evolution and Emerging Policy Issues

Suresh Pal and Derek Byerlee

Introduction

India has one of the largest and most complex agricultural research systems in the world, with more than a century of organized application of science to agriculture. A proactive policy by the government toward agricultural research and education (R&E),[1] coupled with support from a number of bilateral and multilateral donors, has produced an institutionally diverse research system that has achieved many successes, most notably the Green Revolution in the 1960s and 1970s. The country is not only self-sufficient in food but also commands a strong position in world markets for some commodities. Many studies have empirically shown the impressive performance of the system, with annual rates of return to investment in research ranging from 35 to 155 percent (Evenson, Pray, and Rosegrant 1999). Notwithstanding these achievements, the system must now address a more complex and expanding research agenda of sustaining natural resources, enhancing product quality, and ensuring food safety, in addition to increasing household food and nutritional security and reducing poverty. These new challenges require a rematching of needs with resources, and a reorientation of R&E policy.

Redirection of R&E policy and strategy must be in tune with national and international developments. The increasing role of markets, growing participation of the private sector in research, rapid advances in science, and strengthening of intellectual property rights have a significant bearing on the organization and management of agricultural research. The Indian system has also reached a stage where it must address "second-generation problems" relating to organizational rigidities, inefficiencies, and difficulties in sustaining funding. These issues are particularly important in an era of a liberalizing economy, India's entry into the World Trade Organization (WTO), and a tightening of the public purse.

Against this background, this chapter reviews the funding and organization of agricultural R&E in India. After presenting the macroeconomic and sectoral policy context for agricultural development in India, the chapter reviews the historical evolution of R&E policies and institutions and summarizes the current situation. Next it summarizes sources of and trends in public funding and human resources and the allocation of funds to providers of research services. It concludes with a discussion of the emerging policy issues for agricultural R&E in India.

The Context

The Macroeconomic Environment

Following independence, India pursued a socialistic development path, emphasizing heavy industry, import substitution, high levels of protection of domestic industry, public-sector regulation, and public investment. Allocation of capital and foreign exchange was controlled through a highly bureaucratic system of licenses and permits, leading to what was termed the "license Raj" (Das 2001). Although this strategy created a massive industrial base and infrastructure in the public sector, it could generate only a modest economic growth rate (around 3.5 percent per annum) in the first three decades after independence.

By 1991, a mounting balance-of-payment deficit forced the government to implement drastic reforms throughout the economy. These reforms liberalized imports by dismantling the quota system and cutting tariffs, reducing the fiscal deficit, deregulating most industries, and openly soliciting private investment (including foreign direct investment). The reforms were further reinforced by India's commitments as a founding member of the WTO. A second phase of reform covering the financial sector, public-sector organizations, intellectual property rights, and labor regulations has recently been initiated. As a result of the reforms, economic growth accelerated to over 6 percent annually in the 1990s, the economy became more export-oriented, and poverty declined significantly.

Economic reform was not targeted toward agriculture, and in fact liberalization of the agricultural sector has lagged behind that of most other sectors. However, agricultural exports increased significantly, and there was greater participation by the private sector in agricultural input industries like the seed industry. Also, the rate of private capital formation in agriculture accelerated because of improved terms of trade. Investment in infrastructure, R&E interventions in food-grain markets designed to enhance national food security, and various public programs for conservation of natural resources and poverty reduction continued to be high priorities for government support. Subsidies on agricultural inputs, especially water, electricity, fertilizer, and food marketing and distribution, continued at high levels, reaching 7 percent of agricultural gross domestic product (AgGDP) (Gulati and Sharma 1995). However, it is expected that the policy of market-led development will be extended to the agricultural sector, adding urgency to the need to clearly define the role of the state, enhance the efficiency of state interventions, and promote partnerships with the private sector.

Agricultural Development: Issues and Policies

Indian agriculture is highly diversified in terms of both production environments and activities. Smallholder farmers (those of less than 2 hectares) constitute about 80 percent of total farm holdings and occupy 40 percent of the agricultural land area. Despite a rapid increase in livestock production, the crop sector still contributes three-quarters of the total value of agricultural output. Agricultural growth registered a sharp increase in the late 1960s and 1970s as a result of the widespread adoption of the new seed- and fertilizer-based Green Revolution technology for rice and wheat in irrigated areas (Table 7.1). This growth spread to rainfed areas from the 1980s onward, with the adoption of hybrid strains of maize, sorghum, pearl millet, and cotton, although the effects were less widespread, and many areas with harsh growing conditions continue to experience low and unstable production. Average crop yields have increased by an average of 1.6 percent annually over the past three decades as a result of a marked increase in irrigated area and the use of modern inputs (especially seed and fertilizer). Yield growth and increased cropping intensity resulted in impressive growth in agricultural production despite little change in cultivated area. Since 1980, these trends have been echoed in the livestock sector, which has grown even faster, at 5 percent annually, mainly because of rapid growth in milk, poultry, and fish production.

Studies have shown that irrigation, land reform, infrastructural development, and technical change were the main sources of agricultural growth (Desai 1997; Fan, Hazell, and Thorat 1999). Estimates of total factor productivity (TFP) growth for Indian agriculture since the Green Revolution average 1.5–2.0 percent annually, in line with growth in industrialized countries (Murgai 2001; Pingali and Heisey 2001). In addition, the contribution of TFP to output growth has become more important in recent years. Much of the growth in TFP has been attributed to investment in agricultural research that provided high payoffs (Mruthyunjaya and Ranjitha 1998; Evenson, Pray, and Rosegrant 1999).

Table 7.1 India: Trends in agricultural input use and yields, 1961–2004

Indicator	1961	1971	1981	1991	2002
Average size of holding (hectares)	2.69	2.30	1.84	1.57	1.41[a]
Net cropped area (million hectares)	133.2	140.3	140.0	143.0	141.1[b]
Gross cropped area (million hectares)	152.8	165.8	172.6	185.7	187.9[b]
Gross irrigated area as percentage of gross cropped area	18.3	23.0	28.8	33.6	40.0[b]
Fertilizer nutrient use (kilograms per hectare)	1.9	13.1	31.8	67.4	89.8
Food grain production (million tons)	82.0	108.4	129.6	176.4	212.0
Milk production (million tons)	20.0	22.0	31.6	53.9	88.1
Fish production (million tons)	1.2	1.8	2.4	3.8	6.4
Egg production (billions)	2.8	6.2	10.1	21.1	40.4
Percentage of total value of production					
Crops	82.4	84.4	81.4	74.7	71.2
Livestock	17.6	15.6	18.6	25.3	28.8
Percentage of agriculture in					
Total export value	44.3	36.8	35.5	22.5	12.4
Total import value	36.4	37.0	18.3	11.3	6.2
Crop yields (tons per cultivated/sown/harvested hectare)					
Rice	1.01	1.11	1.29	1.74	2.00
Wheat	0.85	1.32	1.71	2.33	2.70
Coarse cereals	0.71	0.85	1.03	0.91	1.14

Sources: Reserve Bank of India 2000; Ministry of Finance, *Economic survey,* various years.

Note: Crop yields are three-year averages—that is, 1961 refers to 1961–63, and so on.

[a]Figure is from 1995 census.

[b]Figure is for 2001.

Overall, India's agricultural achievements are impressive, with increased per capita food production and accumulating food stocks. Despite this success, India still faces many challenges in increasing agricultural productivity. First, to reduce poverty and malnutrition, which are most prevalent in rural areas, India needs not only to improve the availability of food (through higher production and better distribution) but also to generate income and employment opportunities for the poor to provide them with access to food. Second, because accelerated economic growth and rapid urbanization are driving demand for high-value commodities, particularly livestock and horticultural products, future agricultural growth needs to be much more diversified. Third, sustainable management and use of natural resources is a growing challenge, with depletion of groundwater, agrochemical pollution, and land degradation by waterlogging, salinity, soil erosion, and deterioration of soil fertility.

Fourth, public investment in agriculture in real terms has shown a persistent decline, while subsidies for agriculture have increased over time despite the new economic policies. The decline in public investment has serious implications for agricultural growth and poverty reduction (Roy 2001). Fan, Hazell, and Thorat (1999) found that investment in agricultural research provides a high marginal return relative to other investments in terms of both growth and poverty reduction, and this return may now be higher in rainfed areas. Careful targeting of public investment—incorporating subsectoral and regional priorities and efficient use of existing infrastructure, particularly irrigation—is essential for achieving the 4 percent growth per annum contemplated in the current national agricultural policy. However, high levels of subsidies compete with funds available for needed public investment, including investment in agricultural research.

The current national agricultural policy anticipates that market forces will guide future agricultural growth through domestic market reforms, an increasing role for the private sector, and removal of price distortions. The policy of interventions in food-grain markets to stabilize prices will continue, but efforts will be made to make these interventions more effective and efficient by improving management of the Food Corporation of India and by targeting public distribution of food grains to the poor. These reforms, coupled with a focus on value-added and commercialization, and improved product quality and comparative advantage, are essential for successful transition to a knowledge-based and competitive agricultural sector. The role of the agricultural research system will be central in these processes.

Historical and Institutional Development of the Indian Research System

Historical Evolution

The first organized attempt to promote agricultural development, including R&E, in India began in the last quarter of the 19th century with the establishment of the Department of Revenue, Agriculture, and Commerce in the imperial and provincial governments, together with a bacteriological laboratory and five veterinary colleges. Around 1905, the Imperial (now Indian) Agricultural Research Institute (IARI) was established, along with six agricultural colleges.[2] A milestone in the history of Indian agricultural R&E system was the establishment of the Imperial (now Indian) Council of Agricultural Research (ICAR), in 1929, as a semi-autonomous body to promote, guide, and coordinate agricultural research nationally. Between 1921 and 1958, a number of central commodity committees were formed to develop commercial crops: cotton, lac (a hardened resin secreted by lac insects on the leaves of various trees), jute, sugarcane, coconut, tobacco, oilseeds, areca nut (from a palm of the genus *Areca*), spices, and cashews. These committees—also semi-autonomous and financed by government grants and revenues from a levy on the output of each commodity—set up research stations for each commercial crop. Initially, the commodity committees served the interests of the imperial government by providing revenue and ensuring raw materials for industry; later they focused on national development objectives, including research. Participation in the commodity committees was eventually broadened to include producers and representatives of trade and industry.

An important institutional innovation in the post-independence period was the establishment of the All India Coordinated Research Projects (AICRPs), initiated in 1957 under ICAR to promote multidisciplinary and multi-institutional research. The success of the first project for maize led to numerous AICRPs covering all major commodities. The concept also spread to noncommodity research.

In 1965, ICAR was mandated to coordinate, direct, and promote agricultural research in India by overseeing all the research stations previously controlled by commodity committees and various government departments. Subsequently, the Department of Agricultural Research and Education (DARE) was created in the central Ministry of Agriculture to facilitate linkages between ICAR and the central and state governments and with foreign research organizations.

On the recommendation of two joint Indian–American review teams (in 1955 and 1960), state agricultural universities (SAUs) were established, following the land-grant pattern of the United States. The first SAU was opened at Pantnagar in the state of Uttar Pradesh in 1960. The SAUs were autonomous, funded by the government of the respective states; they integrated education with research and (to some extent) frontline extension, although mainstream extension remained the responsibility of the state departments of agriculture.

A number of international agencies played important roles in the development of the public agricultural R&E system in India. Notable among these were the Rockefeller Foundation, which provided support to AICRPs (Lele and Goldsmith 1989), and the U.S. Agency for International Development, which played an active role in the establishment of the SAUs and the training of staff through partnerships with U.S. land-grant universities. The World Bank has provided considerable resources to agricultural research since 1980. The initial phase of this support emphasized the development of research infrastructure and human resources, while recent support has focused on strategic research areas, priority research themes, and institutional reforms.

The Current Structure of the Public Research System

Currently, the public agricultural R&E system consists of ICAR and its various institutes, and the SAUs and their various campuses and regional institutes. At the center, ICAR funds and manages a vast network of research institutes, including national institutes for basic and strategic research and postgraduate education;[3] central research institutes for commodity-specific research; national bureaus for conservation and exchange of germplasm and soil-survey work; and national research centers (NRCs) for applied, commodity-specific strategic research in "mission mode."[4]

In addition, ICAR manages a large number of AICRPs (as mentioned above), which draw scientists from both ICAR institutions and the SAUs. Most AICRPs centers are located on SAU campuses under the administrative control of the respective SAUs. However, for the most important AICRPs (those for rice, wheat, maize, cattle, oilseeds, water, cropping systems, and biological control of pests), ICAR has established special project directorates with their own research infrastructure, under ICAR administrative control, that consist of teams of multidisciplinary scientists.

In 2000, ICAR had 5 national institutes (including an academy for agricultural research management), 42 central research institutes, 4 national bureaus, 10 project directorates, 28 NRCs, and 82 AICRPs (ICAR 2001). In addition, ICAR established 261 *krishi vigyan kendras* (agricultural science centers, or KVKs) at the district level that are responsible for the transfer of new technologies and for training farmers. Some of these KVKs are managed by SAUs and nongovernmental organizations (NGOs). In addition, there are 8 training centers that train the educators in areas such as livestock, horticulture, fisheries, and home science.

There are now 31 SAUs in India with faculties that include agriculture, veterinary science, engineering, and home science. Depending on the nature of the state's agriculture, SAUs may also have faculties of horticulture, fisheries, and forestry, and some SAUs focus exclusively on animal sciences. In addition, there is 1 central agricultural university under ICAR to cater for the needs of small states in northeastern India. SAUs also have zonal research stations to address research problems for each agroclimatic zone.

In addition to the traditional national agricultural research system (NARS)—that is, the ICAR/SAU system—there are nonagricultural universities and organizations that support or conduct agricultural research either directly or indirectly. For example, the departments of biotechnology (DBT), science and technology (DST), and scientific and industrial research (DSIR) under the Ministry of Science and Technology support and conduct agricultural research at their institutes and sometimes fund research in the ICAR/SAU system. Similarly, a number of nonagricultural universities have faculties of agriculture.

Private-Sector Development

Initially, a few private companies dealing with agricultural inputs (pesticides, fertilizers, and machinery, for example) invested modestly in product development, although there was little effort to establish in-house research capacity. The situation changed in the 1980s with the growing availability of trained scientists, rapid expansion of markets for agricultural inputs and processed foods, and liberalized policies to support private-sector development. The private sector now supplies half of all certified seed, half of all fertilizer, and most of the pesticide and farm machinery. Private investment in research currently focuses on hybrid seed, biotechnology, pesticides, fertilizer, machinery, animal health, poultry, and food processing.

The government has provided strong incentives in the form of tax exemptions on research expenditures and venture capital, and liberal policies on import of research equipment to encourage participation of the private sector in research. The most significant development has occurred in the seed sector after the implementation of a new seed policy in 1988, which allowed the importation of seed materials, as well as majority ownership of seed companies by foreign companies (from 1991). A number of foreign seed companies entered the market, and several local seed companies have established considerable research capacity (Pray, Ramaswami, and Kelley 2001). Some local companies collaborate with overseas companies for access to proprietary tools and technologies. Private hybrids now account for a significant share of the market for sorghum, maize, and cotton (Singh, Pal, and Morris 1995; Pray, Ramaswami, and Kelley 2001), and companies with some foreign ownership account for about one-third of this market (Pray and Basant 2001). Developments in biotechnology have further strengthened these trends.

With implications for innovation that are not yet clear, the Indian government recently approved the Protection of Plant Varieties and Farmers Rights Act (2001) to provide intellectual property protection to plant breeders. At the same time, the act emphasizes farmers' rights to save, exchange, and sell unbranded seed of a protected variety. India has also amended the Patent Act (1970) to make it compatible with WTO agreements. A third set of amendments enshrined in the Patents (Amendment) Act (2005) grants process and product patents in all fields of technology. These are likely to stimulate research in the biotechnology and plant and animal health sectors.

Participation of private nonprofit organizations in agricultural research has also increased. There are now a few private foundations, as well as NGOs, actively engaged in agricultural research. In particular, the M. S. Swaminathan Research Foundation and Mahyco Research Foundation have developed considerable research capacity with a national presence and are working in close collaboration with the ICAR/SAU system. In addition, many small, regional, and local NGOs are engaged in agricultural research, such as those managing some ICAR-sponsored KVKs.

Contemporary Developments

The ICAR/SAU system has reached a stage where it needs to consolidate past gains through modernization of research infrastructure, development of human capital, innovations in research management, and stronger linkages with clients. The system is responding to these challenges, albeit to varying degrees and with varying speed (Mruthyunjaya and Ranjitha 1998). Several of these challenges will be addressed in the concluding section of this chapter. Here we note two recent developments: ecoregional research initiatives for research planning, and responses to new science.

Ecoregional Research Initiatives

Although the Green Revolution technologies were rapidly adopted in large areas, further gains in irrigated areas, as well as in rainfed areas that have enjoyed fewer benefits, require more location-specific research to adapt technologies to local and seasonal conditions. The system has been constrained in responding to this challenge because of the limitations of the structure underpinning national or regional ICAR institutes and SAUs due to their strong commodity and disciplinary orientation. Accordingly, an ecoregional approach to planning and organizing agricultural research was introduced in 1978 to better target research efforts, integrate research across disciplines, and locate appropriate sites for research programs. Under the National Agricultural Research Project (NARP), implemented with World Bank funding, the entire country was divided into 126 agroclimatic zones, each consisting of several districts. In each of the zones, a research station was established under a specific SAU to carry out applied and adaptive research relevant to the zone (Ghosh 1991). An advisory committee with a wide representation of farmers, NGOs, and the state department of agriculture was created to link scientists more closely with farmers and other stakeholders, and research programs were developed through a bottom-up participatory approach. These zonal research stations also provided technical support to the KVKs and state extension departments.

The ecoregional approach was further developed under the National Agricultural Technology Project (NATP), again implemented with financial support from the World Bank. Under NATP, the country is divided into 5 ecoregions (arid, coastal, hill and mountain, irrigated, and rainfed), which are further delineated into 14 production systems. Research programs for each of the production systems are identified in a participatory mode and implemented using a multi-institutional and multidisciplinary systems approach. These research programs are intended to complement the AICRPs and the zonal research stations by promoting a systems approach to planning and implementing research.

Biotechnology

Over the past decade or so, revolutionary advances in biotechnology have transformed the way agricultural research is organized and funded. To meet this challenge, the Department of Biotechnology (DBT) was created in 1986 under the Ministry of Science and Technology to support research and human resources and infrastructure development in biotechnology related to agriculture, health care, the environment, and industry. DBT has established 6 autonomous institutions for biotechnology research. It also funds biotechnology research in other institutions, including ICAR institutes and SAUs, through special projects and grants, and through its competitive grants program. In addition, ICAR has developed capacity in biotechnology research in several of its research institutes and has created new entities exclusively for biotechnology research. These initiatives have allowed India to develop considerable capacity in this area of science, although much of it is outside the ICAR/SAU system.[5] At least 10 research institutes have capacity in genetic engineering.

The private sector is also responding to developments in biotechnology, with up to 45 companies active in agricultural biotechnology research (broadly defined) for a market that was estimated to be worth US$75 million in 1997 (Qaim 2001). Both foreign and domestic companies are included, although all of the domestic companies with significant biotechnology programs have developed joint ventures with global companies. At least 3 foreign companies have major biotechnology research facilities in India, 1 with a team of 34 scientists (Pray and Basant 2001).

Given that several genetically modified products are now moving into field testing and commercial release, the government is currently focusing on establishing a framework to regulate biotechnology research and the testing and release of genetically modified organisms (GMOs). The Review Committee on Genetic Manipulation (RCGM) under DBT (comprising members from various scientific organizations) is responsible for monitoring biotechnology research, safety, and the import and export of GMOs. The Genetic Engineering Approval Committee of the Ministry of Environment and Forestry assesses GMOs for environmental safety and approves them for wide-scale testing and commercial release. India has allowed field experiments of GMOs, and commercial cultivation of transgenic cotton was approved in 2002.

Funding of Research

The amount of research funding and the mechanisms for fund allocation are powerful instruments of research policy in India as elsewhere. Most funds for agricultural research in India are allocated through block grants, but funding through competitive grants is now gaining acceptance, especially for operating and equipment costs.

Methods for Allocating Public Funding

Most public funding to agricultural R&E in India takes the form of block grants to ICAR and the SAUs, with allocations determined by five-year plans. At the beginning of each plan, the Planning Commission constitutes a working group to agree on broad agricultural R&E priorities and to assess financial requirements for their implementation. Recommendations of the working group are discussed in several consultations between DARE and the Planning Commission. Based on the outcome of these deliberations, DARE develops its five-year plan, and plan outlays are communicated by the Planning Commission on approval by the Ministry of Finance. Next, five-year plans are developed for each ICAR institute. Depending upon the level of proposed outlays, these plans are evaluated by committees composed of directors of the institutes, senior research managers from ICAR, and representatives of the Planning Commission, Ministry of Finance, and other departments. The approved outlays are the basis for each institute's funding during the plan period, and funds received are demarcated as "plan funds." The ongoing activities of the previous plan are financed under "nonplan funding," which primarily pays salaries and other fixed costs.

A similar procedure is followed for state funding, except that state allocations are first determined by the Planning Commission as part of total plan allocations to states. Both plan and nonplan expenditures on R&E are then approved by the respective state governments.

This process implies that resource-allocation decisions are made through informed opinion and collective wisdom regarding research priorities that address developmental objectives. Institutions are directly involved in the allocation decisions, and other stakeholders are widely consulted. Historical trends also play an important role, especially for nonplan funding.

Use of formal economic methods for allocating agricultural research funds is a recent phenomenon in India. These methods are being tested under NATP for research programs at the ecoregional level. Another innovative method for resource allocation is followed in the AICRPs, which ICAR and SAU fund at the ratio of 75 to 25 percent, respectively. The locations of AICRP centers are decided based on priority ecoregions, and funds are allocated accordingly.

In general, resource allocation appears to have been relatively efficient. Jain and Byerlee (1999) computed a congruency index of 0.88 between value of production and resource allocation in 20 production environments for wheat. The main discrepancy has been the strong tendency for research intensity to be higher in smaller production environments. There is good evidence that resources have shifted with changing production conditions. In the case of wheat, this implies an increase in resources allocated for breeding for late planting and a decrease in resources for rainfed areas, in accordance with increased cropping intensity and irrigation, respectively.

Competitive Funding

Competitive funding is gaining popularity in India. It is regarded as a powerful mechanism to direct funds to high-priority areas, improve quality and accountability, and promote wider participation of research providers and innovative partnerships. There are at least five different competitive funds operating at the national and state levels to support agriculture research. Unlike those of other developing countries, where these funds have been established mostly with donor support, several of the Indian funds were initiated with domestic resources and may therefore be more sustainable (Carney, Gill, and Pal 2000). Although these funds are increasing, they still account for only about 3 percent of public research funding.

ICAR's Ad Hoc Research Scheme, financed by the agricultural cess on selected commercial crops, is the oldest competitive fund, supporting research in emerging areas and research to fill critical technology gaps. NATP's Competitive Grant Program (CGP) and the Competitive Agricultural Research Program (CARP) of the Uttar Pradesh Council of Agricultural Research (UPCAR) are more recent and are donor-supported.[6] The competitive funds of DST and DBT support upstream research in all fields of science, including agriculture. All these funds have similar operational modalities: short-term research projects selected through peer review and provision of funds for operating costs but not for salaries and infrastructure (Table 7.2).

Although these funds are operating quite successfully and are in high demand, a number of issues need to be addressed. Because research priorities are not well defined in the request for proposals, the number of proposals is large, and the success rate is low. (CGP addresses this problem to some extent.) Most operate at the national level, and there is no systematic mechanism to ensure that regional priorities are addressed. This problem, coupled with weak capacity to develop competitive proposals in institutions located in less-developed regions, leads to a low success rate in those regions. More effort is needed to train scientists in weaker institutions in developing research proposals. The experience of CGP has also shown that prompt evaluation is important in attracting quality proposals. Finally, because research projects under competitive grants are time-bound, timely release of funds and efficient administrative procedures are critical.

Table 7.2 India: Important competitive funds for agricultural research

Details	Ad hoc Agricultural Produce Cess Fund; ICAR research scheme	ICAR National Agricultural Technology Project (NATP) Competitive Grant Program	Department of Science and Technology (DST)	Department of Biotechnology (DBT)	Competitive Agricultural Research Program (CARP) of the Uttar Pradesh Council of Agricultural Research (UPCAR)
Institutional base	ICAR headquarters	ICAR headquarters	DST headquarters	DBT headquarters	UPCAR
Size of fund	US$5.8 million (1999–2000)	US$21.1 million over five years (1998–99 to 2002–03)	US$10.5 million annually	US$9.5 million annually	US$2.5 million over five years (1998–99 to 2002–03)
Source of finance	Cess collected by the Government of India under the Agricultural Cess Act of 1940 and 1966 (amendment)	NATP funds of the World Bank	DST budget	DBT budget	World Bank funds
Purpose	To fill critical gaps in scientific fields and address research problems for agriculture and allied sectors through short-term, results-oriented ad hoc research	To support agroecosystem research under NATP with enhanced basic and strategic research; product, process, and market development with greater partnership between public and private sectors	To promote research in frontline science and engineering areas, develop research capacity, and encourage young scientists	To support R&D in biotechnology to achieve excellence and develop new products, processes, patents, and applied technology	To draw on the comparative advantage of research capacity outside state agricultural universities, including the private sector, for synergies and cost-effectiveness through collaboration
Eligibility	All public, recognized private, and nongovernmental organizations capable of undertaking research	All public, private (foundations and companies), and nongovernmental research organizations, and international research centers collaborating with national programs on a cost-sharing basis	Recognized public, private, and nongovernmental organizations capable of undertaking research	Recognized public, private, and nongovernmental organizations capable of undertaking research	Recognized public, private, and non-governmental organizations capable of undertaking research and located in the state of Uttar Pradesh
Components of project grant	Operating expenses, equipment costs, contract staff salaries, and minor civil works in exceptional cases	Operating expenses, equipment costs, contract staff salaries, and minor civil works in exceptional cases	Operating expenses, equipment costs, and contract staff salaries	Operating expenses, equipment costs, and contract staff salaries	Primarily operating expenses; equipment, training, and consultancy costs for basic and strategic research only

Source: Pal 1999.

Overview of Sources of Funding and Fund Flows

Figure 7.1 provides a schematic representation of the sources and flows of funds in the Indian NARS around 2000. Though agriculture is a state responsibility, the central government funded a block grant of US$300.9 million in 2000 through ICAR, which also manages grants and loans from multilateral donors, and collaborative research programs funded by bilateral donors and international organizations. The World Bank is the primary source of such funds. ICAR managed a loan of US$180 million from the World Bank under NATP for strengthening research and extension for the period 1998–2003. A small loan was also provided for human resources development in SAUs in four states (less than US$10 million for 1995–2001).

In addition, ICAR manages the Agricultural Produce Cess Fund, levied at 0.5 percent (ad valorem) on specified export commodities and accounting for about 2 percent of the total ICAR budget in 2000.[7] Finally, with implementation of a new policy on self-generated income (ICAR 1997), ICAR earns some resources through consultancies, contract research and services, sale of seed and other planting material, and royalties on research products through partnerships with the private sector. However, progress has been modest: ICAR generated just 3 percent of its total budget in 2000 through these means.

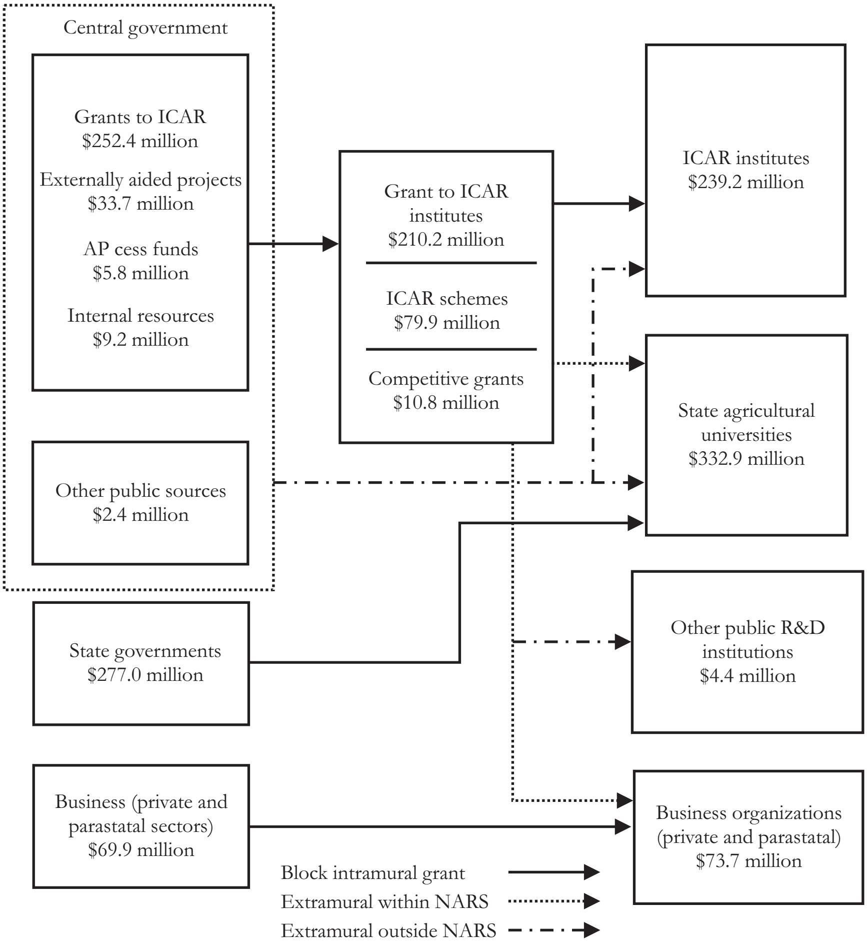
Overall, the central government provides 52 percent of public funding for agricultural R&E in India, almost all of which passes through ICAR.[8] A significant proportion of the ICAR funds (30 percent) is made available for extramural funding (Figure 7.1), and a large proportion of this (87 percent) is directed to the SAUs. Nonagricultural public research institutions and private (profit and nonprofit) research organizations obtain 7 percent and 6 percent, respectively, of ICAR's extramural funding through competitive research programs and support to KVKs.

In terms of funding mechanisms, about 30 percent of the extramural funding from ICAR is disbursed through the AICRPs in the form of block grants, 12 percent through competitive funding, 34 percent through donor-funded projects, 17 percent through grants to KVKs, and 7 percent as development grants to SAUs.[9]

Annual block grants from the state governments to the SAUs totaling US$277 million in 2000 are the second major source of funding. Virtually all of these funds are used intramurally by the SAUs. State funds are not used by ICAR institutes, with the exception of a small competitive fund in Uttar Pradesh that is open to all research organizations in the state, including ICAR institutes.

The remaining significant source of research funds is private firms. Nearly all of this funding is used for intramural research, which accounts for about 11 percent of the total. Private funding of research in public organizations is negligible. The most often cited example was a research contract between ICAR and the Mahyco

Figure 7.1 India: Funding channels for agricultural R&E, 2000



Source: Compiled by authors from various sources.

Notes: Data are in nominal U.S. dollars. State funding data are revised estimates. ICAR funding was apportioned using budget estimates. Private R&D investment data were available for 1997 (DBT 1999), and were extrapolated for 2000 using the growth rate reported in Table 7.5. Extrapolated expenditure on seed research reported in Table 7.5 was also included in this figure, as DST data do not cover private seed research.

Research Foundation for hybrid rice development in 1995. Such linkages could increase in the future because of concerted efforts by ICAR, but they are unlikely to make a significant contribution to total agricultural research efforts in the country for many years.

In terms of spending (the right side of Figure 7.1), ICAR institutes together accounted for 37 percent of the national expenditure on agricultural R&E and SAUs for 51 percent. The remaining 12 percent was spent by other public and private organizations.

Trends in Overall Public Funding for Research

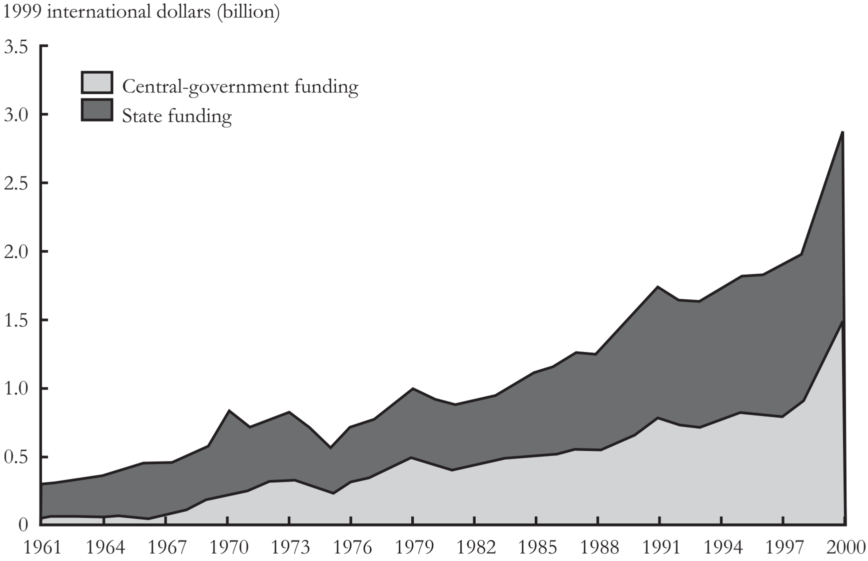
India has consistently committed substantial government funds to research in all fields of science, including agriculture. Figure 7.2 shows the trends in public funding, in real terms, for agricultural R&E in India. Total funding increased in real terms, from $284 million 1999 PPP or international dollars in 1961 to $875 million in 1981. This figure rose to $2.893 billion in 2000 international dollars—a 10-fold increase over the past four decades (Figure 7.2).[10] In nominal terms at the prevailing exchange rate, public funding to agricultural R&E reached US$578 million in 2000. Increases are observed for both central and state funding. Funding from the states grew rapidly during the 1960s, during which time a large number of SAUs were established. Central funding outpaced state funding thereafter until their shares roughly equalized in the 1980s and the 1990s.

Using simplifying assumptions,[11] nearly three-quarters of this total R&E expenditure goes to research (net of education), and research expenditure in absolute terms amounted to $1.898 billion 1999 international dollars in 2000. Overall public research funding grew at 3.16 percent in the 1970s and 7.03 percent in the 1980s, slowing to 4.61 percent in the 1990s. These trends show a continuing, strong political commitment to research despite a pluralistic political system, changes in governments, and shifts in public-investment priorities.

Intensity of Research Funding

Another way to assess funding is to compute various intensity ratios, such as expenditure per agricultural worker, expenditure per unit of agricultural land, and share of agricultural GDP (AgGDP) (Table 7.3). All the intensity ratios registered impressive growth over time despite significant growth in population, land area, and AgGDP. Agricultural research expenditure as a percentage of AgGDP increased significantly during the 1960s and 1980s but remained around 0.3 percent during the 1990s (Figure 7.3).[12] This slowdown is worrying given that the developing-country public-research average is 0.62 percent and the global average is 1.04 per-

Figure 7.2 India: Trends in real public agricultural R&E funding, 1961–2000



Sources: Developed by the authors from expenditure data obtained from the Comptroller and Auditor General of India, various years; the Reserve Bank of India, various years; and the Ministry of Finance, *Finance accounts,* various years. See also Appendix Table 7A.1.

Notes: "Central-government funding" includes funding directed to ICAR institutes and research structures, along with other central-government activities related to agricultural R&D; "state funding" refers to funding of state-government undertakings, which mainly consist of research undertaken by the state agricultural universities (SAUs).

cent (Pardey and Beintema 2001). Part of the difference can be attributed to the relative importance of agriculture and economies of scale and scope in agricultural research (Alston, Pardey, and Roseboom 1998), but there appears to be a clear case of underinvestment in India: China, a country of comparable size and level of development, spent 0.43 percent of AgGDP on research in 1995. Even comparing agricultural research with general science and technology research in India, ICAR received only about 10 percent of total central-government research funds in 1997 (although state funding is more important for agriculture than for other fields).

Funding by States

Table 7.4 gives real growth and intensity of agricultural research funding at the state level. The growth in real funding was highly uneven among states during the 1970s.

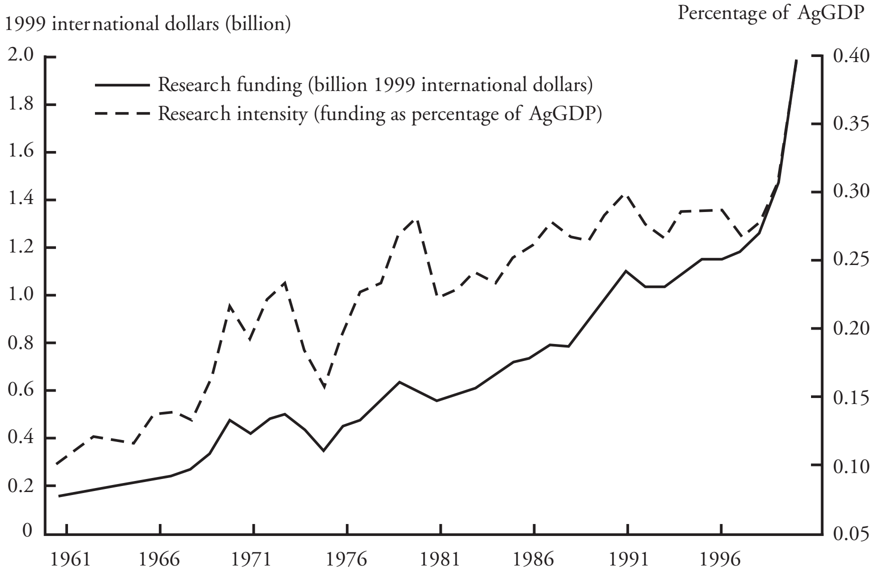
Table 7.3 India: Intensity of public agricultural R&E funding, 1961–99

Indicator	1961–63	1971–73	1981–83	1991–93	1997–99
R&E expenditure					
Constant local currency units (billion 1999 rupees)	2.697	6.576	7.892	14.335	17.885
Total expenditure (million 1999 international dollars)	312	760	912	1,657	2,068
Per capita expenditure (1999 international dollars)	0.71	1.39	1.34	1.97	2.14
Expenditure per agricultural worker (1999 international dollars)	2.38	6.04	6.17	8.94	9.76
Expenditure per hectare of net cropped area (1999 international dollars)	2.29	5.47	6.50	11.75	14.52
Expenditure as percentage of AgGDP	0.20	0.35	0.36	0.44	0.42
Research expenditure (net of education and extension)					
Constant local currency units (billion 1999 rupees)	1.511	4.054	5.057	9.069	11.404
Research expenditure (million 1999 international dollars)	175	469	589	1,049	1,318
Research expenditure as percentage of AgGDP	0.11	0.22	0.23	0.28	0.31

Sources: Developed by the authors from expenditure data obtained from the Comptroller and Auditor General of India, various years; the Reserve Bank of India, various years; and the Ministry of Finance, *Finance accounts,* various years; plus other data obtained from the Government of India and from the Reserve Bank of India 2000.

Note: Figures are three-year averages. See Table 7A.1 for details of international dollars.

Figure 7.3 India: Trends in level and intensity of public agricultural-research funding in India, 1961–2000



Sources: Developed by the authors from expenditure data obtained from the Comptroller and Auditor General of India, various years; the Reserve Bank of India, various years; and the Ministry of Finance, *Finance accounts,* various years.

Table 7.4 India: Growth and intensity of agricultural R&E funding by state governments, 1972–99

State	Annual growth rate in real funding (percent)			Funding per hectare (1999 international dollars)		Funding per agricultural worker (1999 international dollars)		Funding as percentage of AgGDP		Percentage of total funding by all states
	1972–81	1982–91	1992–99	1981–83	1995–97[a]	1981–83[b]	1991–93[b]	1981–83	1997–99	1997–99
Andhra Pradesh	11.40	6.47	5.23	3.03	9.02	2.11	3.48	0.16	0.28	8.08
Assam	–0.07	9.51	–0.03	7.36	11.06	NA	10.13	0.28	0.33	2.84
Bihar	18.52	8.55	5.10	3.00	8.32	1.42	1.86	0.13	0.25	4.96
Gujarat	0.61	9.71	4.78	3.24	9.85	4.72	8.33	0.19	0.41	7.52
Haryana	28.56	5.16	8.18	8.16	22.69	13.17	16.66	0.28	0.44	6.23
Himachal Pradesh	–0.09	12.76	10.21	17.42	65.64	NA	18.46	0.62	1.52	3.31
Jammu and Kashmir	–0.08	10.97	12.79	8.48	34.12	5.66	NA	NA	NA	2.25
Karnataka	12.91	7.54	3.03	2.61	6.02	3.04	4.48	0.19	0.28	5.74
Kerala	25.40	5.23	1.85	11.57	28.08	8.97	17.13	0.31	0.41	5.65
Madhya Pradesh	–0.08	13.29	1.09	0.60	2.10	0.74	2.16	0.07	0.14	3.42
Maharashtra	0.74	7.06	2.43	4.86	9.82	5.89	7.75	0.39	0.43	14.21
Orissa	7.75	6.50	–0.02	1.65	3.22	1.55	3.02	0.10	0.21	1.78
Punjab	3.43	10.28	2.41	8.40	17.92	12.33	19.28	0.24	0.30	6.48
Rajasthan	3.63	10.95	3.58	1.11	3.22	2.34	4.11	0.12	0.18	4.13
Tamil Nadu	3.80	13.00	7.44	4.18	18.52	2.07	5.24	0.21	0.59	9.34
Uttar Pradesh	–0.06	5.74	2.06	3.31	5.21	2.37	3.00	0.13	0.16	8.03
West Bengal	12.13	2.35	4.73	5.34	7.57	3.48	3.07	0.17	0.17	4.89
Average for all states	1.34	8.23	3.82	3.45	7.86	3.27	4.99	0.19	0.24	100[c]

Sources: Developed by the authors from expenditure data obtained from the Comptroller and Auditor General of India, various years; the Reserve Bank of India, various years; and the Ministry of Finance, *Finance accounts,* various years; plus other data obtained from the Government of India and from the Reserve Bank of India 2000.

Notes: Funding intensities and shares represent annual averages for the respective periods. See Table 7A.1 for details of international dollars.

[a] Computed using triennium average of NCA, ending in 1997.

[b] Computed using census data for agricultural workers for 1981 and 1991, respectively.

[c] Excludes small share representing expenditure for small states.

These differences narrowed in the 1980s, with steady growth in all states. Total state funding increased from 1.3 percent per annum in the 1970s to 8.2 percent in the 1980s, slowing to 3.8 percent in the 1990s. The intensity of state funding has increased in all states except West Bengal since the 1980s. However, wide variation persists between states with comparatively high ratios, over 0.4 percent of AgGDP (Himachal Pradesh, Tamil Nadu, Haryana, Maharashtra, Gujarat, and Kerala) and states with very low ratios, under 0.2 percent (Madhya Pradesh, Rajasthan, Uttar Pradesh, and West Bengal).

A host of factors may explain variations in the intensity of agricultural research. (Rose-Ackerman and Evenson 1985; Judd, Boyce, and Evenson 1986; Alston, Pardey, and Roseboom 1998). Pal and Singh (1997) applied a political-economy model to analyze the determinants of the level of state funding to agricultural research in India using cross-sectional and time-series data for the period 1982–94. Although the results were mixed, and unmeasured state-specific attributes were important, per capita state funding was found to be strongly related to per capita AgGDP, indicating that states with higher income levels spend comparatively more on agricultural research. Rural literacy and the share of agriculture in government expenditure also had a positive and significant effect on research intensity. Other factors, such as sources of growth in agriculture (for example, expansion of agricultural land and irrigated area), crop diversification, and terms of trade, were insignificant. It seems that the availability of public resources and the importance assigned to agriculture have important consequences for the amount of public funding directed toward agricultural research.[13]

Donor Funding

The U.S. Agency for International Development (USAID) has been a significant funder of agricultural research. USAID supported SAU development from the early 1960s until 1977. Its support peaked in the 1980s, when a major agricultural research project was under way (Alex 1997). In total, USAID invested some US$108 million (in 1999 prices) in Indian agricultural research until about 1990, when support was terminated.

Beginning in 1980, the World Bank became a significant supporter of agricultural research at the state and zonal levels, and from 1997 at the national level. The World Bank has also supported human-resource development in the SAUs since 1995, and a number of state projects have financed agricultural research, especially in Rajasthan and Uttar Pradesh. In total, the World Bank has provided US$538 million (in 1999 prices) to agricultural research since 1975 (Appendix Table 7A.2).[14]

One important implication of these results is that in low-income countries like India, donor support to agricultural research can help increase intensity levels.

However, long-run funding sustainability depends on India's giving higher priority to agricultural research investment over nondevelopment expenditures, many of which are subsidies. This is particularly true when the rates of returns to agricultural research are found to be high.

Private Research Funding

The recent rapid growth in private research spending in India has outpaced the capacity to track its intensity, orientation, and impact. Based on broad estimates for each subsector (seed, pesticide, machinery, livestock, and food processing), total private or business funding for agricultural research (including funding by state-owned enterprises) in India doubled from an estimated US$24 million in 1985 dollars to US$51 million in 1995 (Table 7.5),[15] or from $119 million to $253 million in 1999 international dollars. Private research funding has grown at 7.5 percent, compared with 5.1 percent in the public sector over the same period, and accounted for 11 percent of total funding of agricultural research in 2000 (Figure 7.1).

Table 7.5 shows that the largest investment has occurred in pesticides and food processing, followed by seed, fertilizer, and machinery. The most rapid increases in private growth have occurred in food processing, seeds, veterinary products, and sugar. More recently, there has also been strong investment in biotechnology, animal health, and the poultry sector. This has been accompanied by significant growth in research expenditure by multinational companies.

Table 7.5 India: Agricultural research expenditures by private firms and state-owned enterprises, 1984–95

	Research expenditure (million 1995 U.S. dollars)		Research expenditure (million 1999 international dollars)[a]		Annual growth rate (percent)[a]	Share in state enterprises (percent)
Industry	1985	1995	1985	1995	1985–95	1995
Seed	1.33	4.93	6.62	24.55	13.1	0
Machinery	3.70	6.48	18.43	32.27	5.61	13
Fertilizers	6.80	6.65	33.87	33.12	–0.22	67
Pesticides	9.00	17.02	44.82	84.76	6.37	15
Veterinary	0.90	2.72	4.48	13.54	11.06	5
Sugar	0.90	2.49	4.48	12.40	10.17	1
Food processing	1.34	10.47	6.67	52.14	20.56	1
Total	23.97	50.75	119.38	252.78	7.50	16

Source: Pray and Basant 2001.

Note: See Table 7A.1 for details of international dollars.

[a] Calculated by authors.

Providers of Research: Human Resources and Patterns of Expenditures

Human Resources for R&E

Although precise and consistent estimates of scientific staff in the ICAR/SAU system over time are not available, the number of scientists working in the ICAR/SAU system during the late 1980s was estimated to be 4,189 at ICAR and 14,851 at the SAUs, totaling 19,040 (ICAR unpublished management records). The number of scientists remained steady at ICAR during the 1990s (4,092 in 1998) but decreased significantly at the SAUs (17,678 in 1992); it has likely fallen further since that time through attrition.

Adjusting the number of scientists by share of research expenditure relative to extension and education (for ICAR) and share of time spent on research (for SAUs), the number of full-time equivalent (fte) scientists in the late 1990s was 2,999 within ICAR and 8,132 within the SAUs. This amounts to a total of 11,131 fte researchers nationally, in line with staffing levels in the United States (Table 7.6). This is a substantial increase from the estimated 5,666 fte researchers in the ICAR/SAU system in 1975, and 8,389 in 1985 (Pardey and Roseboom 1989).

The educational qualifications of Indian researchers are also impressive: about two-thirds of researchers hold Ph.D. degrees, and the balance hold M.Sc. degrees. The proportion of female researchers is very low, however—7.5 percent within ICAR and 2.1 percent in the SAUs.

Scientific staff are supported by a large number of technical and administrative staff. The ratio of scientists to administrative staff is especially high in the universities, at 1:2.5. ICAR and the SAUs (to a lesser extent) are attempting to balance these numbers by reducing administrative staff.

Resource Expenditure Patterns

In terms of research expenditures, in 2000, 37 percent was spent by ICAR institutes, 51 percent by SAUs, and the remaining 12 percent by private and other public organizations. By comparison, ICAR provided about half the funding, resulting in a net flow of funds from ICAR to SAUs, largely through the AICRPs. A more disaggregated analysis of expenditure patterns by providers of R&E is difficult, as India has no ready means of tracking the allocation of overall expenditures below the institute level. However, a number of proxies are used in this section to gain insights into the overall allocation of expenditures.

Strategic versus Applied Research

Funding allocation can be examined by R&E type (strategic, applied, and adaptive research, and extension and education) by reviewing the mandates of research

Table 7.6 India: Composition of research staff and allocation of R&E expenditure within ICAR and SAUs

Indicator	Indian Council of Agricultural Research (ICAR) 1996–98	State agricultural universities (SAUs) 1992
Number of researchers	4,092	17,678
Number of full-time equivalent researchers	2,999	8,132
Education levels of researchers (percent)		
Ph.D.	68.8	62.6
M.Sc.	31.2	35.7
Female researchers (percent)	7.5	2.1
Ratio of scientific to technical and administrative staff	1:1	1:2.5
Allocation of expenditure[a] (percent)		
Research	73.3	45.0
Education	5.2	33.0
Extension	6.1	5.0
Other (administration, publications, recruitment, and so on)	15.4	17.0

Sources: ICAR data compiled by authors from ICAR records; SAU data from Rao and Muralidhar 1994.

Note: For ICAR, full-time-equivalent researchers are calculated based on the share of total expenditures on research; for SAU, full-time-equivalent researchers are based on the share of time devoted to research.

[a] ICAR expenditure also includes externally aided projects.

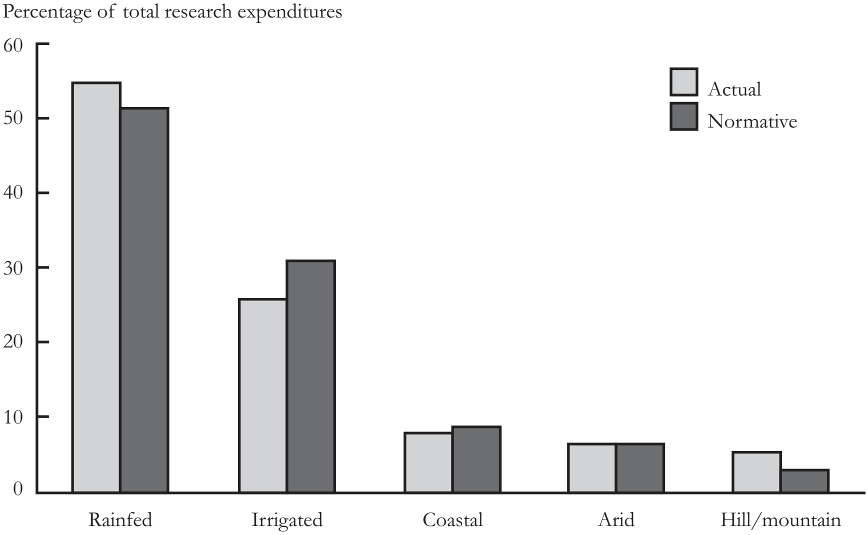
providers.[16] On this basis, basic and strategic research (conducted mainly within ICAR institutes) accounted for 21 percent of total agricultural R&E expenditure, and applied and adaptive research (conducted by ICAR institutes, SAUs, and AICRPs) accounted for 53 percent. Of the balance, 20 percent was spent on education and human resources development (mostly by SAUs), and 6 percent was allocated to frontline extension-related research in ICAR institutes and SAUs, including KVKs (meaning assessment, transfer, and refinement of new technologies).

While these expenditures seem reasonably well distributed, weakening of the basic and strategic research in the system remains a cause for concern. In addition, research capacity in the SAUs is slowly eroding: retiring faculty are not being replaced because of inadequate funding from the states.

Favored versus Less-Favored Regions

The irrigated ecoregion received high priority during the Green Revolution, primarily because of its high growth potential. This focus resulted in a quantum leap in crop yields, but it neglected rainfed and marginal lands. This disparity was corrected in the Seventh Plan (1985–90), which gave high priority to research for rainfed agriculture.

Figure 7.4 India: Allocation of research expenditures by environment, 1996–98



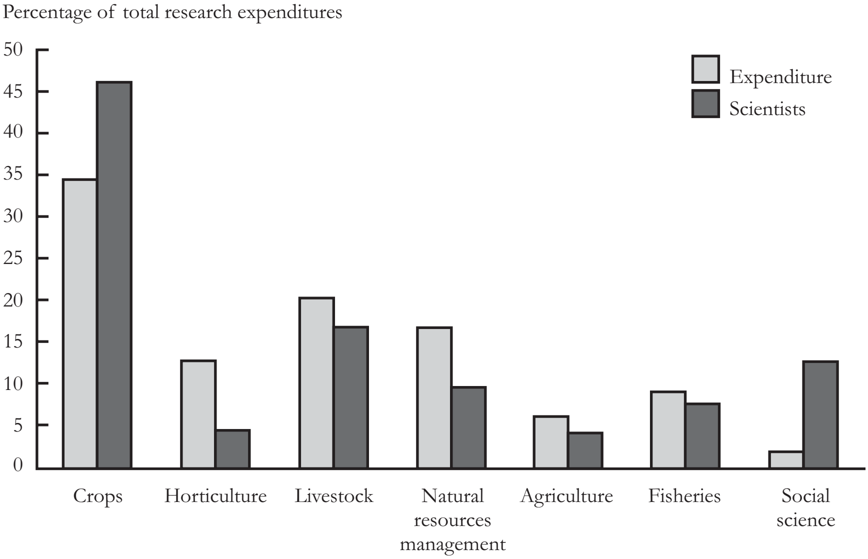
Source: Computed by authors.

To see whether past imbalances have been corrected, we compared actual research expenditure in different ecoregions with the normative allocation using the congruence rule (value of production), modified by criteria for sustainability (area under degraded lands) and equity (number of illiterate females).[17] The estimates in Figure 7.4 show no indication of underinvestment in less-favored ecoregions. Contrary to general belief, less-favored environments received slightly more resources than those justified by the efficiency criterion, even after the inclusion of natural resources and equity concerns that favored allocation to rainfed areas. These very broad observations are supported by an analysis of resource allocation for wheat by Byerlee and Morris (1993), who used the number of field experiments as a proxy for investment by agroclimatic zone. They found that despite the predominance of irrigated wheat and its high research payoffs, there was no evidence of underinvestment in marginal environments. This conclusion was further reinforced by a detailed study by Traxler and Byerlee (2001), which showed that rainfed and hill environments accounted for 30 percent of resource allocation to wheat-breeding research, although these environments only produced 12 percent of all India's wheat. More revealing is the estimate that these research programs for rainfed and marginal areas produced only 1.3 percent of the benefits generated from wheat research in India during the post–Green Revolution period, 1976–93.

Allocation by Subsectors and Commodities

Data on research expenditure by subsector and commodity are available only for ICAR, but they include research expenditure on AICRPs in SAUs.[18] Together these represent 67 percent of total research expenditures in the ICAR/SAU system. Within ICAR, crop research received the highest proportion, followed by animal sciences and natural resource management (Figure 7.5). Recall that the normative allocation pattern based on value of production (see footnote 12) indicates that crop research should receive 51 percent of resources, followed by animal science (including fisheries) at 28 percent and horticultural crops at 21 percent.[19] Both livestock and horticulture are high-growth subsectors that might justify slightly more resources than indicated by value of production, although this argument might be counterbalanced by the fact that livestock research is known to be less location-specific, with higher spillovers.

Figure 7.5 India: Subsectoral allocation of research resources within ICAR, 1996–98



Source: Computed by authors.

Accountability and Research Impact

A number of monitoring and evaluation mechanisms have been instituted at the national, system, institute, and project levels to ensure the relevance of research and accountability in the use of public funds. At the national level, the Planning Commission and various government committees monitor progress and achievements during the preparation of annual and five-year plans. At the regional level, eight committees, made up of representatives from ICAR, the SAUs, and government departments, assess the status of agricultural research in the regions (covering several states) and make recommendations on research priorities. At the institute level, management and research advisory committees oversee administrative and financial matters, advise on research programs, and monitor progress. In each ICAR institute, a staff research council that includes external expert reviewers evaluates research projects.

An external review team undertakes a more substantive external review of each ICAR institute and SAU every five years. The review process covers organizational, management, scientific, and other matters relating to effectiveness, efficiency, and the relevance of the institute. In addition, for SAUs, a committee determines the norms for accreditation and financial assistance from ICAR and periodically assesses performance against the norms.

Through these mechanisms, accountability for the use of public funds is kept high. However, questions are often raised (especially in recent years) about the effectiveness and impact of the research system, despite its success in leading technological innovation in the agricultural sector. Many studies have examined the impact of agricultural research in India by estimating internal rates of return to investments (Table 7.7). Most have analyzed returns to crop research, individually or for the entire subsector. Although there is considerable variation, the average return was about 70 percent, with a median value in excess of 50 percent. Interestingly, there is no evidence that the rate of return has declined since the Green Revolution. The studies have also shown that returns to public research investments have been higher than those for public extension or private research (Evenson, Pray, and Rosegrant 1999).

These results provide a convincing case for enhancing public funding to agricultural research. This point has been made repeatedly by research leaders to build the case for higher budget allocations, particularly during five-year plan preparation. These efforts have achieved some success, as demonstrated by the steady rise in public funding to agricultural research over the past two decades despite the fiscal restraint adopted by the government during the 1990s.

It should be noted that high aggregate rates of return may be hiding considerable inefficiencies in the Indian public research system. Traxler and Byerlee (2001),

Table 7.7 India: Internal rates of return to research investment (percent)

Measure	Aggregate analysis	Analysis for individual crops	All
Mean	75.4	69.9	71.8
Median	58.5	53.0	57.5
Minimum	46.0	6.0	6.0
Maximum	218.2	174.0	218.2
Number of studies	10	18	28

Sources: Based on information in Alston et al. 2000 and Evenson, Pray, and Rosegrant 1999.

Note: Mode could not be calculated because no value is repeated in the observations.

analyzing rates of return to 20 wheat breeding programs across 50 research stations, found that although the aggregate rate of return to wheat improvement research in India from 1978 to 1991 was estimated to be 55 percent, eight programs had negative rates of return when spillins were taken into account. Research output was concentrated in the two strongest programs, which generated 75 percent of all benefits even though they claimed just 22 percent of research resources. Clearly there is considerable scope for increasing the overall return on research investment by redirecting money from unproductive research programs.

Emerging Policy Issues

Agricultural research policy must respond to a changing agricultural, scientific, and economic environment. In the industrialized countries, agricultural research reforms originated from the declining importance of agriculture in the economy and the rapid increases in private research investments. These reforms included separating research funding from research execution, encouraging competitive allocation of funds, improving the accountability of research institutions, and shifting near-market research to the private sector (Alston, Pardey, and Smith 1999). The new paradigm underscores pluralistic institutional structures, new sources and mechanisms for research funding, organization and management reform of public institutions, and management of intellectual property (Byerlee 1998).[20] These same reforms are generally proceeding more slowly in developing countries, where there is a large proportion of small-scale farmers and the public sector still dominates the research system (Byerlee 1998). Thus the focus of research policy should remain on improving efficiency of the public research system and encouraging participation of the private sector where possible.

Balancing Multiple Research Objectives

The Indian NARS must balance multiple objectives, from food security to emerging demands to serve a more market-oriented economy to meeting the needs of more sophisticated consumers and preserving the environment. Striking this balance has major implications for organizing research, setting research priorities, and managing intellectual property.

The public sector is under increasing pressure to provide public-good technologies that address market failures and various social and environmental objectives. This demand puts further pressure on scarce research resources, and hence public research investment in India needs to redress its large shortfall against the global average investment of 1 percent of agricultural GDP. Further, public research institutions must work closely with key stakeholders to define priorities that employ formal research prioritization approaches to address multiple objectives. This is extremely important with such a large system, where objectives conflict and clients have difficulty articulating their research needs. A starting point would be careful tracking of current resource allocations, making necessary adjustments as priorities change.

Center versus State Roles

The distinction between the roles of the center (including ICAR institutes and research structures, along with other central government activities related to agricultural R&D) and the state government undertakings (mainly via the SAUs) in agricultural research has become blurred. In practice, SAUs should have primary responsibility for applied and adaptive research to meet local demands, and ICAR should take the lead in overarching strategic and applied research, in which states tend to underinvest because of spillovers. However, SAUs are generally starved for operating funds and largely dependent on ICAR. A shortage of SAU funding has had adverse effects on human resources development, research infrastructure, and linkages with farmers. There is an urgent need to make policymakers at the state level aware of the payoffs to investing in research. At the same time, the central government might develop a funding formula to support the economically weaker states and provide incentives to the stronger states to increase their funding (for example, through matching grants).

A key role of central research is to generate spillovers to enhance efficiency in state research programs. In some areas, especially crop breeding, spillovers are pervasive. The AICRPs provide a mechanism for facilitating such spillovers. For example, Traxler and Byerlee (2001) found that spillovers from IARI's wheat research program accounted for a large share of the benefits from wheat breeding research in India following the Green Revolution.

Toward a More Pluralistic System

The modern concept of a NARS emphasizes a pluralistic system of research that recognizes the comparative advantages of different providers and the complementarity that can be achieved by forging close linkages among different actors. The leadership of ICAR has noted these requirements and taken a number of initiatives to promote such linkages (Mruthyunjaya, Pal, and Bawa 2000). But effective implementation needs greater awareness further down the line. In particular, the growing role of private research and the implications for public institutions are not widely appreciated. Where the private sector can efficiently provide near-market research services with scope for appropriation of benefits, the public sector should play a complementary rather than a dominant role. Private research is stimulated by strategic research support from the public sector, and there are many areas where public–private linkages can enhance the effectiveness of both sectors. Enabling institutional mechanisms, especially intellectual property rights (IPR) protection and capacity within the public sector to manage partnerships, can help develop and sustain these linkages (Hall et al. 2002).

Sustainability of Research Funding

The Indian public NARS has been relatively successful in increasing government funding for R&E. However, the current funding situation is not sustainable, for a number of reasons. First, because funding has not kept pace with the continuing expansion of the number of R&E institutions, the share of salary and overhead expenditures has gradually increased at the expense of operating expenditures (Pal and Singh 1997). In ICAR, the ratio of salary to operational expenses has increased to 70:30, compared with a target of 60:40, and the situation is even more serious for the SAUs. Second, although competitive funding has increased, it still accounts for only a minor share of total funding. Because competitive funding has the potential to enhance the accountability, quality, and efficiency of the system despite somewhat higher overheads and time costs, a higher share of funds should gradually be shifted to competitive funding. Of course, regular block grants must continue to support research infrastructure and strengthen basic and strategic research.

Finally, new resource-generation opportunities could be tapped, including payments for services by farmers growing high-value crops (commercial livestock and fruit crops), income generation through commercialization of technology and services, and contract research with the private sector. ICAR has set a goal of deriving 25 percent of its budget from these sources by 2020. Achieving this goal will require the development of capacities in IPR and business skills in public research organizations. ICAR has already developed such a policy, and the government has offered matching grants for self-generated income as an incentive.

Challenges of Modern Science

Although India has developed relatively good capacity in new areas of science, especially biotechnology, these new undertakings have raised a number of challenges:

the development of research capacity, biosafety and IPR regulations, and management of public dialogue on controversial issues.

Establishment of biotechnology capacity is relatively capital- and human-resource-intensive. Although it is expected that the private sector will be active in biotechnology in India, the public sector will have to play a dominant role, especially for noncommercial agriculture. Therefore, mechanisms to access proprietary technologies by using resources in the public sector (such as germplasm) as bargaining chips and segmentation of markets deserve special attention. Also, given the number of public and private institutions involved, there is much potential for forging public–private linkages to enhance productivity. These include sharing of costs and benefits, joint ventures, and management and ownership of intellectual property.

Advances in biotechnology have also blurred the differences between general sciences and the agricultural sciences, requiring close linkages with general science and technology providers. These are the more necessary when the major responsibility for promotion of biotechnology in India rests with DBT in the Ministry of Science and Technology.

Given the current debate on biotechnology in India and elsewhere, effective biosafety regulations must be in place that are credible, cost-effective, and properly coordinated. Biosafety is the single biggest constraint to application of transgenic technology in India, which still has only just released its first product for commercial use (*Bacillus thuringiensis* cotton), despite many years of research and many products in the pipeline. A consideration often neglected is the provision of information about these new technologies to farmers (Tripp and Pal 2001). Since much of this information is a public good, public institutions will have to take responsibility for providing information to farmers and educating consumers.

Organization and Management Reforms in the Public Sector

The public sector in India is generally overly centralized and bureaucratic, creating high transaction costs at all levels. Despite a certain level of autonomy, the research system is no exception. Although ICAR recognizes these problems and has initiated a number of organizational and management reforms, important gaps and implementation problems still exist. First, institutional rigidities imposed by commodity and disciplinary boundaries restrict the flow of information between hierarchies and organizations in a large system such as India's. The decision to review the functioning of the AICRPs—originally established to forge interdisciplinary and interinstitutional research—was an important step toward addressing these rigidities (ICAR 1999).[21] But much remains to be done to decentralize and devolve power before transaction costs can be reduced to acceptable levels for efficient research management.

Second, the lack of movement of research staff within the system or among ICAR, the SAUs, and other agencies (with the problem being particularly acute for SAU scientists) inhibits the overall quality of researchers. Scientific linkages with institutions and individuals outside India are deteriorating. In the 1960s and 1970s, a significant proportion of scientists were educated abroad, and Indian scientists were generally well integrated with regional and international networks. This situation has deteriorated significantly, with scientists often working in the institution from which they received their Ph.D., professionally isolated from developments internationally and even elsewhere in India. This trend must be arrested. One possibility is to earmark greater shares of foreign grants and loans for human-resource development and to support participation by researchers in international scientific networks and other initiatives. Advances in information and communication technologies also have the potential to foster linkages and improve access to international literature and scientific databases.[22] At the same time, performance-based evaluation linked with incentives and rewards is long overdue.

Third, research institutions require improved accountability through the institutionalization of objective and transparent evaluation mechanisms for research planning, monitoring, and impact assessment. The proliferation of research programs has meant that many programs serving small states and agroecological zones are inefficient. Much of the inefficiency found in the Traxler and Byerlee (2001) study results from research programs serving small ecologically and politically defined markets, so that even if they are productive in terms of the technologies produced, they are used only in a small area. Resource allocation needs to be linked to research planning based on bottom-up approaches involving relevant stakeholders and feedback from monitoring processes and impact assessment. Implementation of such processes has been attempted several times, with varying degrees of success. Effectiveness depends on harmonization across the planning, monitoring, and evaluation phases, the decisionmaking process for funding, and performance-evaluation procedures at all levels.

Although successive ICAR review panels have raised these concerns and recommended changes, past attempts at reform failed because of a lack of financial flexibility and autonomy. A package of reforms aimed at enhancing autonomy, improving decentralization and devolution of power, and improving financial management through project-based budgeting is required. Both ICAR and the SAUs should commit to such reforms. Support from high level policymakers at both central- and state-government levels is needed if this far-reaching reform agenda is to succeed.

Technology Transfer

It is generally agreed that payoffs to agricultural research could be much higher with a stronger research-extension interface. The weaknesses of the current system can be attributed to a number of factors. First, because adaptive research and technology transfer is considered to be less challenging, few scientists are attracted to it. Second, scientists working in technology assessment and transfer are disadvantaged because performance-evaluation criteria tend to emphasize the number of publications. Third, most scientists lack the skills to assess farmers' research needs and design appropriate technologies; they also lack operating expenses for on-farm research. In addition, supply-driven extension approaches focused on the public sector in India are long overdue for a drastic overhaul. Strategies of improving accountability to clients through various incentive schemes in the research system and piloting more pluralistic, demand-driven extension systems are now receiving priority as a means of speeding technology transfer.

Conclusions

The Indian agricultural research system has a long and distinguished history that evolved from a decentralized, imperial system into a highly centralized one created to respond to the food crisis in the 1960s. With the goal of increased food production as the driving force, the system grew rapidly, through both central and state fiscal appropriations. The impacts of this investment were impressive: India became self-sufficient in food, and numerous studies documented high payoffs.

In the 1990s, new challenges arose, forcing changes in the organization and funding of research in India. Food security is now only one of several goals of the research system. Globalization and rapid developments in science, privatization and liberalization of the economy, and challenges of sustainable resource management and diversification are now placing new demands on the system.

Clearly a strong central research system is still required, but the role of this system must evolve to focus on upstream and strategic research to generate spillovers at the national level. Other actors will play an increasing role in the system, especially the SAUs, general science research institutes, and the private sector. The articulation of actors in this more diverse and decentralized NARS is evolving. Inevitably there will be tensions that must be resolved, such as the effort to organize research along agroecological lines to enhance efficiency, while at the same time attempting to attract funding at the local level within the context of politically defined administrative boundaries.

Even with a rapidly expanding private sector in agricultural research, the public sector will continue to play a dominant role for many years to come. However, the efficiency and effectiveness of the public sector will depend on critical policy changes and institutional and management reforms to drastically improve its performance. These reforms must center on autonomy, decentralization, financial flexibility, and accountability. The proposed reforms are not new, but their implementation must be streamlined at two levels. First, policymakers must acknowledge the need for reform to keep pace with global changes. Second, the public research system requires an internal paradigm shift that links funding to research outcomes by improving the relevance of research through participatory approaches and instituting a performance-based incentive and reward system. Finally, there is a need for much greater awareness of the development, protection, commercialization, and application of intellectual property and technologies in enhancing research impact and access to modern scientific tools.

Some important lessons can be learned from the Indian NARS. First, political commitment through sustainability of public funding is essential. The Indian system has ably demonstrated this over the long term, despite the transition at independence and successive governments of different political ideologies thereafter. However, as the system expands and becomes more complex, a number of organizational and management problems emerge. The system has also shown that these problems could be addressed with appropriate management leadership and a willingness to learn from the past, as well as from contemporary institutional developments in research systems around the world.

Appendix Table 7A.1 India: Public funding for agricultural R&E, 1961–2003

	Research and education				Research only[a]
Year	Current prices (million rupees)	1999 prices (million rupees)	Current prices (million international dollars)	1999 prices (million U.S. dollars)	Current prices (million rupees)
1961	126.00	2,407.70	294.12	58.36	70.62
1962	142.41	2,609.42	318.76	63.24	80.30
1963	158.47	2,690.23	328.63	65.20	88.23
1964	184.83	2,888.84	352.89	70.02	101.49
1965	223.26	3,234.07	395.06	78.38	122.21
1966	266.93	3,411.62	416.75	82.69	143.03
1967	306.47	3,606.50	440.56	87.41	170.42
1968	358.98	4,126.40	504.07	100.01	205.59
1969	431.34	4,797.28	586.02	116.27	256.58
1970	645.13	7,062.50	862.73	171.17	373.70
1971	555.62	5,775.11	705.47	139.97	337.00
1972	637.08	5,971.45	729.45	144.73	396.45
1973	747.77	5,945.06	726.23	144.09	463.21
1974	768.34	5,234.53	639.43	126.87	476.03
1975	709.37	4,908.89	599.65	118.98	445.54

(*continued*)

Appendix Table 7A.1 (continued)

Year	Research and education				Research only[a]
	Current prices (million rupees)	1999 prices (million rupees)	Current prices (million international dollars)	1999 prices (million U.S. dollars)	Current prices (million rupees)
1976	885.17	5,780.83	706.17	140.11	561.56
1977	1,005.67	6,220.76	759.91	150.77	641.84
1978	1,219.98	7,360.76	899.16	178.40	786.91
1979	1,414.06	7,368.06	900.06	178.58	914.98
1980	1,523.43	7,118.74	869.60	172.54	984.02
1981	1,623.60	6,880.60	840.51	166.76	1,030.91
1982	1,875.57	7,378.55	901.34	178.83	1,199.65
1983	2,075.41	7,498.60	916.00	181.74	1,343.55
1984	2,432.76	8,182.28	999.52	198.31	1,568.98
1985	2,830.89	8,882.41	1,085.04	215.28	1,811.15
1986	3,197.21	9,395.41	1,147.71	227.72	2,026.08
1987	3,645.81	9,810.18	1,198.38	237.77	2,309.46
1988	3,944.67	9,801.41	1,197.31	237.56	2,488.02
1989	4,825.58	11,066.57	1,351.85	268.22	3,026.72
1990	5,825.75	12,085.63	1,476.34	292.92	3,666.70
1991	7,137.03	13,008.52	1,589.07	315.29	4,520.13
1992	7,717.98	12,924.15	1,578.77	313.24	4,887.72
1993	8,329.44	12,740.20	1,556.30	308.78	5,258.00
1994	9,599.61	13,386.57	1,635.25	324.45	6,080.95
1995	11,063.24	14,157.44	1,729.42	343.13	7,018.51
1996	12,149.85	14,498.55	1,771.09	351.40	7,679.70
1997	13,663.07	15,307.66	1,869.93	371.01	8,526.88
1998	15,156.88	15,739.85	1,922.72	381.49	9,632.26
1999	19,925.17	19,925.17	2,433.99	482.92	12,908.57
2000	23,820.93	22,950.87	2,803.60	556.26	15,819.11
2001	25,853.60	23,981.61	2,929.51	581.24	16,823.44
2002	25,204.49	22,597.76	2,760.46	547.70	16,425.02
2003	26,799.77	23,176.48	2,831.16	561.73	17,296.82

Sources: Data in current local currency compiled by author from Ministry of Finance, *Finance accounts*, various years; Reserve Bank of India, various years; and other data.

Notes: Data are actual expenditures. International dollars are obtained by currency conversion using purchasing power parity (PPP) indexes in conjunction with rupee-denominated expenditures. PPP indexes are the purchasing power of currencies by comparing prices among a broader range of goods and services than conventional exchange rates.

[a] See footnote 11 for details on constructing research only series.

Appendix Table 7A.2 India: Annual international lending for agricultural R&E, 1963–2002

Period	USAID (million U.S. dollars)	World Bank (million U.S. dollars)	Total (million U.S. dollars)	Total (million 1999 international dollars)
1963–65	3.24	—	3.24	6.15
1966–77	2.84	—	2.84	7.10
1978–85	4.94	17.15	22.09	57.76
1986–91	4.12	27.46	31.59	106.13
1992–97	—	7.78	7.78	36.51
1998–2002	—	37.94	37.94	192.94

Sources: USAID data from Alex 1997; World Bank data calculated from unpublished World Bank files.

Note: A dash indicates either negligible or no expenditure. Data may not tally exactly with those in Figure 7.1, because these are averages. See Table 7A.1 for details of international dollars.

Notes

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1. In India, agricultural research and education are carried out mainly in the same institutions, and for the most part they are treated together in this chapter. Agricultural research also includes some frontline extension, consistent with the mandate of the national agricultural research system. Further, in this chapter, agricultural research includes research on crops, livestock, fruits, plantation crops, fisheries, and agroforestry, but not forestry, for which there is a separate research system.

2. One college established in Faisalabad is now in Pakistan, and the others are at Pune and Nagpur (Maharshtra), Kanpur (Uttar Pradesh), Sabor (Bihar), and Coimbatore (Tamil Nadu).

3. Four national institutes are recognized as "deemed university," meaning that they offer regular postgraduate degree courses in their respective fields of specialization in addition to conducting research.

4. "Mission-mode" research is multidisciplinary research directed toward the development of technologies or components of national importance. NRCs are smaller than other institutes and organized into multidisciplinary teams.

5. Only 8 of the 18 public institutes identified by Qaim (2001) as having significant capacity in biotechnology are part of the traditional NARS (6 within ICAR and 2 within the SAUs).

6. The CGP has developed a systematic and rigorous procedure for evaluating proposals, based on objective criteria like research relevance, researcher competence, scientific quality, probability of research success, and equity concerns, such as development of marginal areas, poverty alleviation, and gender impact.

7. India's financial year begins in April and ends in March. Data are reported on a year's-end basis; hence 2000, for example, refers to 1999–2000.

8. The other central-government funding is through the Ministry of Science and Technology (DBT and DST).

9. Estimates of funding transfers through competitive grants, KVKs, and externally aided projects are available in ICAR's budget records. AICRP funds were apportioned based on the ratio of centers located in SAUs and within ICAR institutes (70:30) (ICAR n.d.).

10. Pal and Singh (1997) compiled the research funding series in India for 1961 through 1995 from various government publications. These data series were used with minor refinement and updates for subsequent years from the same sources (Comptroller and Auditor General of India, various years; Ministry of Finance, various years; Reserve Bank of India, various years; and Reserve Bank of India 2000). The nominal expenditure data were first converted to constant 1999 local currency (Indian rupees) using the implicit GDP deflator. These data were then converted to 1999 international dollars using a purchasing power parity (PPP) conversion factor of 8.65.

11. Separating research expenditure from total research and educational expenditure is difficult, particularly for SAUs. Using survey estimates for one year for SAUs (Rao and Muralidhar 1994) and information available in ICAR budget documents, the share of "research" expenditure (net of education and frontline extension) was calculated as 80 percent for ICAR and 50 percent for SAUs (see Table 7.7). In the absence of time-series data on these shares, constant shares were used to estimate a time series on "research" expenditures.

12. Our estimates are considerably lower than estimates reported by the IFPRI–ISNAR ASTI initiative for earlier periods because the latter series included expenditures for agencies deemed to be outside the agricultural research system for the purposes of this study. See http://www.asti.cgiar.org.

13. A similar conclusion was drawn in another study analyzing the determinants and impact of public investment in Indian agriculture (Roy 2001).

14. These are conservative figures for World Bank and USAID assistance. Since we assumed that most donor aid is spent in foreign currency, the data were also deflated with the U.S. GDP deflator, in addition to being converted to international dollars.

15. The Pray and Basant (2001) private-sector data include spending by nonprofit producer organizations, whereas Pardey and Beintema (2001) included research done by these entities as part of public research. Distinguishing research from product promotion and extension expenditures is a major difficulty when constructing private-sector research data.

16. For institutions with multiple R&E categories, such as the SAUs and the national institutes of ICAR, total expenditure was first apportioned using the respective shares of R&E categories (see note 12). Research expenditure was then apportioned into basic, applied, and adaptive research based on the mandate of the institution.

17. These estimates are taken from a research prioritization exercise undertaken by the senior author for NATP. Since ecoregions do not correspond with state boundaries, total state research expenditure was apportioned to different ecoregions within the state based on their shares of crop area for crop research, net sown area for noncommodity research, livestock population for animal science research, and state-level production for fisheries research.

18. The number of scientists working on AICRPs is 3,862 (ICAR 1999), and most of them are in SAUs (ICAR n.d.).

19. These normative, commodity-based allocations also include research expenditures on natural resource management, social science, and agricultural engineering, which are common to all commodities.

20. See several papers on the evolution of national agricultural research systems in a special 1998 issue of *World Development* (26/6).

21. The committee recommended that AICRPs for crops or resources with applicability in different agroclimatic zones should be continued, and others should be phased out or converted to networks. It also suggested streamlining the AICRPs' priority-assessment and review processes.

22. As noted earlier, some efforts in this direction were made under AHRD and NATP, but these need to be streamlined and upscaled.

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Chapter 8

South Africa: Coping with Structural Changes

Frikkie Liebenberg and Johann Kirsten

Introduction

Analyzing the evolution of agricultural research and development policy in South Africa is a fascinating but difficult task, primarily because of the large number of structural, institutional, and political changes that took place during the 20th century. This chapter tracks the history of South Africa's agricultural research and development system against this background, highlighting changes over the past 20 years. Such changes have enabled better documentation of public spending on R&D and assessments of changes in the methods by which those funds are disbursed.

Public-sector financing remains the dominant source of funding, but, as in so many countries, public funding has come under severe pressure in recent years. In recent years, contributions by producer organizations and international donors to the funding of agricultural research have increased, and universities play a much greater role as research providers. Declining core government funding and changes in leadership and management styles have driven large numbers of the most highly qualified researchers out of South Africa's primary research provider—the Agricultural Research Council (ARC). The prospect of the demise of the agricultural research system led to an initiative to coordinate the funding and provision of agricultural research in South Africa through a National Agricultural Research Forum (NARF).[1]

This chapter presents South Africa's agricultural research and development policy within this historical framework. In the next section we provide a brief overview of the agricultural sector and a review of policy changes with a view to highlighting the increased flexibility in input substitution, to which the research system has likely contributed. Thereafter we provide an overview of the overall science and technology policy and a detailed account of agricultural R&D policy focusing on the institutional structure, priority setting, sources of support, and agricultural R&D providers. We conclude by discussing major lessons learned and summarizing the debate on a more sustainable national agricultural research system for the future.

Overview of South African Agriculture

Macroeconomic Environment

South Africa is a lower-middle-income country where approximately half the population lives in poverty.[2] According to the results of the 1996 census, the South African population is estimated at 40.584 million, with population growth of about 2 percent per annum—down from 2.5 percent per annum during the 1980s. The census results indicate that total employment in the economy is 9.1 million, of which about 1.8 million are informal job opportunities.[3] About 34 percent of the economically active population of 27.8 million people are unemployed and seeking work.[4] The rural unemployment rate for South Africa is 44.2 percent (the urban unemployment rate is 28.7 percent). The Development Bank of Southern Africa (DBSA 2000) estimates that 57 percent of the South African population live in poverty; May (2000) estimates that 30 percent of the urban population are poor, but poverty rates are highest, at about 70 percent, outside urban areas. Many rural people in South Africa live under conditions of deprivation as harsh as those in poorer African countries.

With the fall of the apartheid regime, the government undertook a commitment to reduce rural poverty and adopted programs of land reform and improved service delivery in rural areas. Program results, although commendable in some respects, have been insufficient, slow, and costly relative to expectations and the scale of the task. In the meantime, rural areas face new challenges as the crisis of HIV/AIDS reduces resources flowing to households and severely increases the pressures on families and communities.

Overview of the Agricultural Sector and Changing Productivity

Primary agriculture, which consists of farm-based production, accounted for 3.4 percent of the GDP of South Africa in 2004 (Table 8.1). Gross value of agricultural production is estimated at 66 billion rand[5] in 2001–02—an increase of 30.9 percent over 2000–01. Animal products made up 35.3 percent of this figure, field crops 41.0 percent, and horticulture 23.7 percent (Table 8.2). The most important

Table 8.1 South Africa: Indicators of structural change in the economy, 1970–2004

Indicator	1970	1975	1980	1985	1990	1995	2000	2004
Value-added as percentage of gross domestic product at basic prices								
Agriculture	7.2	7.7	6.2	5.2	4.6	3.9	3.2	3.4
Industry	35.7	38.9	45.4	39.6	36.1	31.3	28.8	24.7
Manufacturing	22.8	22.7	21.6	21.8	23.6	21.2	18.5	20.0
Construction	4.1	5.1	3.2	3.5	3.3	3.2	3.0	2.4
Mining of mineral resources	8.8	11.1	20.6	14.2	9.2	7.0	7.3	7.1
Services (tertiary sector)	54.7	51.2	45.4	51.2	55.3	61.3	65.2	64.9
Per capita income (rand at current prices)	548	1,034	2,114	3,822	7,861	13,656	20,596	28,823
Exports of goods and services as percentage of GDP at market prices	21.8	27.7	35.4	31.5	24.7	23.0	27.9	26.6
Goods (percent)	18.6	23.8	32.3	28.5	21.7	19.9	24.1	22.7
Services (percent)	3.2	3.9	3.0	3.0	3.0	3.1	3.8	3.9
Imports of goods and services as a share of GDP at market prices (percent)	25.3	30.2	27.3	22.6	18.8	22.1	24.9	27.1
Goods (percent)	20.8	25.3	23.3	18.7	15.4	18.1	20.5	22.7
Services (percent)	4.5	4.8	4.1	3.9	3.3	4.0	4.4	4.4
Employment (thousands)[a]								
Agriculture			1,306	1,181	1,224	810	964	NA
Industry			2,760	2,681	2,785	2,217	2,111	NA
Mining			836	744	841	542	384	NA
Manufacturing			1,464	1,380	1,417	1,120	1,207	NA
Construction			460	557	527	555	520	NA
Services			2,722	2,723	3,642	3,791	3,190	NA

Sources: SARB n.d.; labor statistics are from NDA 2005.

Notes: NA indicates data not available. For employment data, 1980 data exclude the former independent states and homelands of Transkei, Bophutatswana, and Venda; 1985 and 1991 data also exclude Ciskei; 1996 data include the former Transkei, Bophutastwana, Venda, and Ciskei (TBVC) states. Employment data for 1995 and 1999 apply to the age group 15 to 65.

[a] 1991 data used for 1990, 1996 for 1995, and 1999 for 2000.

Table 8.2 South Africa: Trends in agricultural output and yields, 1970–2000

Indicator	1970	1975	1980	1985	1990	1995	2000
Average size of holding (hectares)	987.6	1,102.0	1,338.9	1,307.7	1,427.4	1,349.1	1,794.3
Gross cropped area (thousand hectares)		10,212	10,625		12,900		
Gross irrigated area as percentage of gross cropped area		10.9	7.8		10.5		
Food grain production (thousand tons)[a]	11,000	10,010	17,696	10,899	11,469	13,693	13,844
Milk production (million liters)	1,276	1,376.5	1,471	1,731	1,993	2,149	1,926
Egg production (thousand tons)	107	166	162	195	262	339	361
Meat Production (thousand tons)							
Red meat	9,755	6,756	7,395	8,058	9,763	5,408	4,803
White meat	121	294	364	474	587	708	796
Pork	81	87	89	107	131	127	121
Poultry[b]	40	207	275	367	456	582	675
Total fruit (thousand tons)	2,319	2,667	2,947	3,081	3,860	4,041	4,777
Vegetables (thousand tons)	1,728	2,028	2,418	2,786	3,207	3,575	3,748
Sugar (thousand tons)	330	341	384	411	375	404	429
Percentage of total gross value of agricultural production							
Field crops	46.7	41.7	48.5	40.2	34.7	36.5	30.8
Horticulture	17.3	17.5	14.4	18.8	21.9	23.3	26.4
Animal production	36.1	40.7	37.1	41.1	43.4	40.2	42.7
Percentage of agriculture							
In total exports	30.3	31.4	10.3	6.5	8.7	7.9	8.8
In total imports	5.2	4.6	2.6	5.7	5.0	6.9	6.1
Crop yields (tons per hectare)							
Maize	1.8	1.5	3.3	1.8	2.3	2.7	2.7
Wheat	0.7	1.0	0.9	0.9	1.1	1.5	2.4
Grain sorghum	1.5	1.5	2.5	1.3	1.8	3.1	3.1
Sunflower seed	0.7	0.9	1.6	0.9	1.0	1.3	1.4
Groundnuts	0.7	0.5	0.7	0.4	0.8	1.1	1.4

Sources: NDA 2003 and SSA 1985.

[a] Food grain production equals the sum of maize, wheat, grain sorghum, sunflower seed, and soybean.

[b] Poultry is estimated as the difference between total white meat production and pork production.

earners of foreign exchange in the agricultural sector are sugar, wine, citrus, and deciduous and subtropical fruits. The agrofood complex, which consists of primary production plus the input and agroprocessing sectors, accounts for around 14 percent of GDP. In 2000 the agrofood complex exported about R16 billion worth of primary and processed food products, nearly 9 percent of South Africa's total exports (Table 8.2).

There are about 60,938 large commercial farmers, who are predominantly but not exclusively white. Commercial farms employed about 1 million workers in 1999, which is 8.1 percent of total formal-sector employment (NDA 2003). Many of these workers live on commercial farms, and their children are educated in farm schools. Thus commercial farms provide livelihoods, housing, and education for the nearly 6 million family members of these 1 million employees.

Furthermore, an estimated 1.3 million households, primarily located in the communal areas of the former homelands, largely produce to meet part of their family's overall needs. Finally, almost all the productive and social activities of rural towns and service centers are dependent on primary agriculture and related activities, which include the increasingly popular and economically significant agrotourism and game farming. Taking all of these activities into account, more than half the provinces, and about 40 percent of the country's total population, are primarily dependent on agriculture and its related industries.

A Review of Policy Changes in South African Agriculture

Deregulation and liberalization were distinctive features of the agricultural sector of South Africa during the 1980s.[6] The deregulation process was characterized by changes within the existing institutional structure, through a process of scaling back state intervention. Despite these changes, the main actors in the sector remained the same. This situation changed with the election of the Government of National Unity in 1994, although in agriculture, at least, some direct policy changes were stalled until 1996 (until after the withdrawal of the National Party from the Government of National Unity). The most important policy initiatives taken subsequently included land reform, institutional restructuring in the public sector, the promulgation of new legislation (including the Marketing of Agricultural Products Act and the Water Act), and trade and labor market policy reform. These reforms were intended to correct the injustices of past policy (principally through land reform), to direct the agricultural sector toward a less capital-intensive growth path, and to enhance the sector's international competitiveness.

One of the main features of South African agricultural policy in the 1990s was institutional restructuring. The public-sector agencies supporting the agricultural sector were subjected to the same processes of "provincialization" that came about with the adoption of the Interim Constitution. In the case of agriculture, the former "own affairs" (whites-only) and "general affairs" departments were amalgamated to form the core of the new National Department of Agriculture. Functions and staff were redeployed from the former homeland departments of agriculture to new national and provincial departments, and the relationship between the national and provincial departments of agriculture and farmer lobby groups was modified.[7]

Agricultural institutions in the public sector were also reoriented in line with new policy directions. The most radical of these changes occurred in agricultural marketing policy. The promulgation of the Marketing of Agricultural Products Act, No. 47 of 1996, represented a radical departure from the marketing regime to which farmers had been accustomed since the 1930s (Groenewald 2000). Though far-reaching, the deregulation of the 1980s and early 1990s was piecemeal and uncoordinated, and was accomplished within the framework of the old Marketing Act so that policy changes could be reversed easily. The new act changed the way agricultural marketing policy would be managed.

The new South African government also embarked on a process of trade policy reform to reverse decades of "inward industrialization" strategies. The distinguishing characteristic of these reforms was a willingness to expose national businesses to tariffs that were often below the lower bounds negotiated in the Uruguay Round of the General Agreement on Tariffs and Trade (GATT). Whereas agricultural trade had been managed through quantitative controls, the Marrakech Agreement called for the tariffication of all agricultural goods and a phased reduction in the tariffs. South Africa also participated in the renegotiation of the Southern African Customs Union treaty, agreed to the new Southern African Development Community (SADC) trade protocol, and negotiated a free trade agreement with the European Union. In all these cases, the country agreed, in principle, to liberalize agricultural trade further. Finally, the country gained membership in the Cairns Group,[8] thus signaling its intention to unilaterally liberalize its trade regardless of progress made by developed countries in withdrawing farm support programs.

Effects of policy changes. These policy changes created a number of pressures on farm profits. The analysis of total factor productivity (TFP) in South African agriculture presented below clearly shows that farmers adapted to these changes by decreasing their level of input use, by increasing output from a constant level of input use, or by a combination of these approaches. Whatever the case, productivity has increased. In South Africa, real gross annual capital formation—which was fairly stagnant in the 1980s—has increased at a higher rate since 1990 (Table 8.3). Thus, since the beginning of the 1990s, farmers have reacted positively to political changes,

Table 8.3 South Africa: Growth in employment and capital formation, 1947–96

Period	Change in number of farm employees (percent per year)	Real gross capital formation (percent per year)
1947–96	0.16	2.01
1947–80	1.16	2.65
1980–96	−1.86	0.68
1990–96	−4.22	7.79

Source: Thirtle and van Zyl 1994.

greater access to international markets, and positive real interest rates. The TFP ratio provides a more comprehensive measure of productivity growth in agriculture. The TFP for commercial agriculture in South Africa to 2000 is shown in Figure 8.1, from which it is evident that input use increased slightly faster than the growth in agricultural output from the late 1940s to late 1960s, and so TFP declined. Thereafter, the pace at which aggregate output grew exceeded the growth in aggregate input use (which actually began to decline around 1986–87) and so

Figure 8.1 South Africa: Total factor productivity growth for commercial agriculture, 1947–2000

Source: Thirtle 2001.

TFP rose. Thirtle (2001) described these trends and some ancillary developments in more detail:

- The domestic terms of trade for intermediate and capital goods for commercial farmers were negative throughout the period 1960–96, and hence the input prices they paid rose faster than the output prices they received throughout that period.
- The rate at which the domestic terms of trade turned against commercial farmers worsened during the first phase of deregulation (from roughly 1984); they improved subsequently but were still far higher than between 1960 and 1980.
- The terms of trade measure the rate of change in the prices of intermediate and capital goods relative to the rate of change in output prices only. TFP measures the relative rate of growth in the value of inputs (including land and labor) and outputs. The data show that TFP growth slowed during the first phase of deregulation, between 1985 and 1994, and increased again thereafter.
- From 1980 through 1990, when inflation rates in South Africa peaked and TFP growth was weakest, net farm income growth was negative (that is, commercial farmers' profit margins grew thinner every year). However, by 1990 TFP growth had recovered sufficiently to cause a positive annual growth in net farm income through 1996.

These TFP results reflect the extent to which farmers have reacted to the cost–price squeeze, and it is clear that one of the principal solutions was to change not only the volume of inputs used but also the input mix. Thus farmers' ability to adopt new modes of production depends critically on their ability to substitute inputs in reaction to relative price changes. Some years ago, research showed that farmers' ability to substitute inputs was severely constrained by state intervention in the sector but that this situation had improved as a result of the first stages of deregulation during the 1980s (van Zyl and Groenewald 1988; Sartorius von Bach and van Zyl 1991). Overall, there is some evidence of improved flexibility in input substitution in South African agriculture.

Overall R&D Policy and Funding Trends

Like the rest of its economy, the South African science and technology institutions (SETIs) have experienced momentous policy changes since the early 1990s. Prior to 1994, SETIs were funded under a policy of "framework autonomy," introduced in 1988. Reduced to its essentials, framework autonomy entailed the following elements:

- The determination of so-called maximum average expenditure per full-time equivalent (fte) staff member (divided into three categories), which was monitored by the Science Council

- The provision of baseline funding, that is, "costs of . . . basic infrastructure (expertise and other capacity) necessary for the realization of the aims of the institution" (DNE 1988, p. 43) based on expenditure for those essential activities in 1986–87, annually adjusted in line with appropriate inflation indexes and the available money

- The provision of discretionary financing of, for instance, the agency function, meaning funding of research in the higher-education sector, the operation of national facilities, and so on

In summary, the system of framework autonomy was designed to restrict government control to the *overall* framework within which the science councils operated, while restricting parliamentary funding to supporting the essential research infrastructure. Within this framework, science councils were given the management flexibility to generate additional income from contracts, and, thus, within limits, to shape their own research agendas.

Each SETI received its budget from its overseeing department (the National Department of Agriculture, for ARC) according to the baseline funding formula. Based on its own internal processes and priorities, the management of SETI allocated its own resources. Science policy was drafted by the Chief Directorate of Science Planning under the Department of National Education (DNE), after which comments from major stakeholders were invited, processed, and submitted to the Science Advisory Council (SAC) for amendment and approval.

Although subject to ARC guidance, the different research institutes were left with significant freedom in setting their own research agendas, in collaboration with industry and peer-review committees. By 1994 these processes still reflected those in existence under the former Department of Agriculture.

In 1994, the Department of Arts, Culture, Science, and Technology (DACST) was established from the relevant elements of the DNE. The creation of DACST introduced a period of rapid changes in science and technology policy in South Africa. Two prominent initiatives taken by DACST since its inception were the

Table 8.4 South Africa: Allocation of the science budget, 1996–97 and 1999–2000

Science Council	1996–97 (million rand)	1999–2000 (million rand)	Nominal change (percentage)
Agricultural Research Council (ARC)	319.10	279.24	–12
Human Sciences Research Council (HSRC)	87.63	64.42	–26
National Research Foundation (NRF)	138.12	162.00	17
Medical Research Council (MRC)	57.91	79.57	37
Council for Mineral Technology	82.77	81.77	–1
Council for Geosciences	63.56	63.79	0
Council of Scientific and Industrial Research (CSIR)	274.36	310.65	13
South African Bureau of Standards (SABS)	45.93	73.72	61
Total	1,069.37	1,115.16	4

Source: DACST 2001.

formulation of a white paper on science and technology (completed in 1996) and the establishment for the National Advisory Council on Innovation (NACI) (legislation approved in 1997). The new policy places a strong emphasis on innovation, and hence on the direction of research resource allocation.

The science and technology branch of DACST took over the administration of an annual budget allocated under the "science vote" of approximately R1.4 billion.[9] Following the white paper, the principle of baseline funding according to a base formula was replaced, and SETIs now receive their core funding through a parliamentary grant allocated on a competitive basis.

Other sources of funding available to SETIs are the innovation fund and the National Research Foundation (NRF), established in 1998 from the former Foundation for Research and Development. The purpose of the innovation fund is to encourage and enable long-term extensive innovation projects in the higher-education sector, SETIs, civil society, and the private sector. The NRF is mandated to ensure the support of research and the building of research capacity within the higher-education sector and other research institutions. For both undertakings, funds are allocated on a competitive basis. It is envisioned that the innovation fund will grow to about 20 percent of the annual budget, forming a strong mechanism to reallocate resources within the national system of innovation (NSI).

Table 8.4 provides an indication of the government funds earmarked for the different science councils for 1996–97 and 1999–2000. It shows a shift away from agricultural and human sciences toward the Medical Research Council (MRC) and the Council for Scientific and Industrial Research (CSIR).

In 1999–2000 the science budget also included R78.3 million for national facilities, such as the National Laser Centre, and a further R146 million for other programs, such as the innovation fund (R75 million) and special investigations

(R33 million). The growth in the innovation fund was paid for from the institutional funding of the science councils, with dire consequences for its sustained capacity development. The priority-setting criteria are not favorable to primary agricultural research: they focus, for example, on third-generation biotechnology.

Financing and Provision of Agricultural R&D

We provide a brief history of the agricultural research system in South Africa to put the system's current policy and structural changes in perspective.

Institutional Structure

Prior to 1990.[10] Following the establishment of the Union of South Africa in 1910, public interventions in agriculture were the responsibility of a central Department of Agriculture. The department also held responsibility for education and training in agriculture. In 1958, the Department of Agriculture was split into two to form the Department of Agricultural Economics and Marketing and the Department of Agricultural Technical Services. The latter focused on production issues and provided services such as agricultural research, education, extension, and regulatory services. In 1962, the Department of Agricultural Technical Services was reorganized as two directorates: the Directorate of Agricultural Research and the Directorate of Agricultural Field Services. The Directorate of Agricultural Research was given responsibility for 10 research centers and directorates that later became institutes. There were also 7 regionally based adaptive research and extension institutes, called agricultural development institutes (ADIs), each with centers for delivering extension services.

Further institutional changes took place in 1970, the most significant of which was the transfer of administrative responsibilities for the faculties of agriculture and veterinary sciences to the Ministry of Education. The Department of Agricultural Technical Services continued to finance research at the universities and supported a substantial, though declining, number of research positions at the various faculties of agriculture.

In rationalizing the public service, the two departments of agriculture were amalgamated in 1980 to form the Department of Agriculture and Fisheries, which was renamed the Department of Agriculture and Water Supply in 1982. Following the establishment of the tricameral legislature,[11] the department was again divided in 1984 to form the Department for Agricultural Development, largely incorporating the branches of the old Department of Agricultural Technical Services, dealing with "own affairs," and the Department of Agriculture, for "general affairs."

All funding for research came through the Department of Agricultural Development, which was initially responsible for 11 research institutes, and later 12. The overall direction of research was mostly determined centrally but was guided by regional development plans. This approach resulted in problems with administration and overall coordination. Links with nationally based institutes, focused on strategic or basic research, and the ADIs also became problematic. The agricultural research system of South Africa at this stage followed a mostly bureaucratic and top-down approach to technology development and transfer.

In a 1984 report by the Committee of Inquiry into Agricultural Service Provision, eight alternative models for the delivery of agricultural research were proposed. The preferred option was the creation of a national agricultural development council. The apartheid dispensation and the various independent homeland governments created problems for its full implementation. ARC (the Agricultural Research Council) was established as a first step toward such a system.

1990 to 1994. Most of the agricultural research activities under the Department of Agricultural Development were transferred to ARC beginning in April 1992, following the passing of the Agricultural Research Act of 1990. This process was completed only in 1995. Thus, by the end of this period, ARC had yet to develop an identity as an organization. The lack of consolidation left ARC incapable of facing the changes in South Africa's constitution and in its own governance structure following the democratic elections of 1994.

More important than the reorganization itself, a business-like management style was introduced into ARC institutes. ARC embarked upon a more aggressive cost-recovery program by introducing a user pays principle. This change introduced a stronger client orientation. Targets were set to rapidly increase external funding, with the goal of recovering 30 percent of total expenditures from the commercial agricultural sector (Roseboom et al. 1995). This shift happened much more rapidly than planned as a result of successive cuts in the parliamentary grant to the ARC.

Following the new constitutional dispensation in 1994, nine provinces were created from the former four, and agriculture became the joint responsibility of the national and provincial governments. The previous agricultural development institutes (ADIs) formed the basis of the nine provincial departments of agriculture (PDAs), although the Grootfontein Agricultural Development Institute became the responsibility of the National Department of Agriculture (NDA), where it still resides, because of issues relating to its location.

Funding of agricultural R&D now came from two streams: ARC received its funding through the National Department of Agriculture, and the PDAs were allocated a portion of the former national agricultural budget according to a formula. The provincial legislature was not compelled to honor this formula, however.

The current situation. The present structure of the South African national agricultural research system (NARS) consists of agricultural research institutes operating under the ARC, departmental research entities, faculties of agriculture and veterinary sciences, institutes operating under the Department of Environmental Affairs, the Council of Scientific and Industrial Research (CSIR), and some semipublic research agencies supported by industry (see Appendix Table 8A.1). ARC is the principal national agricultural research entity. It oversees 13 agricultural research institutes with a network of experimental farms and modern equipment throughout the country, and, with the exception of sugarcane, supports all the major agricultural commodities in South Africa.

Two groups were created to coordinate and integrate these efforts: MINMEC, an interministerial committee headed by the national minister of agriculture and comprising the members of the provincial executives of agriculture, and the Interdepartmental Technical Committee on Agriculture (ITCA), comprising department heads. ITCA had several subsidiary technical and advisory committees. Most of these were disbanded for lack of effectiveness, except for those dealing with natural-resource management and veterinary services. In early 2003 the Agricultural Economics Working Group was reintroduced by ITCA.

Funding for the PDAs and, as such, for provincial agricultural research began to deviate from the 1995 formula guidelines. Provincial R&D capacity dwindled and in some cases ceased. High costs and poor restructuring plans led to the disappearance of agricultural research in some provinces, such as the Eastern Cape. A reasonable degree of research competence exists in only two provinces—the Western Cape (Elsenburg) and Kwazulu-Natal (Cedara)—but these programs remain severely underfunded in some aspects. Most of the provinces had to rely on donor funding and the operations of NGOs and producer or commodity organizations. ARC has provided increasing support to the provinces.

The management of ARC has changed substantially since the new science and technology policy was introduced in 1997. Following various reviews of the agricultural research system and strong criticism of the way ARC was managed, the governance structures were changed, and a number of research institutes were merged. One of the important criticisms was that ARC research dealt mainly with capital-intensive farming operations, thereby benefiting commercial farmers rather than farmers from previously disadvantaged communities. The reviews and recommendations required a shift in research focus and service provision by the ARC while its parliamentary grant dwindled in line with the perceived new direction in the science system. Changes in leadership, among other factors, left ARC increasingly isolated and its stakeholders uninformed of the consequences of these changes. It is possible that ARC's council, being relatively inexperienced, did not foresee and clearly communicate the consequences of the changes satisfactorily. To become an active and integrated member of the country's agricultural research system, the ARC was under pressure to improve its performance and ensure the relevance of its research.

This process involved interactions with a number of stakeholders during 1999. In a series of meetings with PDAs and representative bodies in organized agriculture, stakeholders were asked to critique ARC's performance as an agricultural service provider. Insights gained from this exercise enabled ARC to initiate strategic workshops on its research agenda and on the funding of agricultural research. A system was also introduced whereby research on the problems and needs of resource-poor farmers was detached from the overall parliamentary grant and managed under a separate program for sustainable rural livelihoods. In addition, commercialization of research outputs was given greater emphasis.

Setting Priorities

Oversight of the national system of innovation is the responsibility of the National Advisory Council on Innovation (NACI), which was established to advise DACST on the direction of scientific research. This entity, together with the requirements of the new Public Finance and Management Act (PFMA), plays a major role in influencing research priorities. Under this new act, and in line with the existing medium-term expenditure plan, public entities like ARC are expected to submit three-year budget requests directly linked to strategic plans.

Within ARC, the national institutes previously relied primarily on peer reviews and institute-level priority setting under a regime of (mostly) state-funded research, with the relative share of government funding for each institute remaining fairly stable. The change to the national system of innovation, followed by the subsequent cuts in core funding, mandated a change in the relative share of core funding among institutes. The introduction of corporate programs in 1999 was seen as both a means to drive greater integration in research activities between institutes within a systems-research framework, and a framework to introduce interinstitute priority-setting mechanisms. However, the significant differences in the ability of industries and other clients to pay for research and the severity of the cuts in core funding have led to current core funding ratios that reflect the ability to pay rather than any serious national priority considerations.

Research priorities are also determined by DACST's recently completed national research and development strategy. This department has also been split into two separate departments, with the Department of Science Technology now being responsible for the science vote (DST 2002). This national strategy identifies research needs in all sectors of the economy, including agriculture and agribusiness. These priorities influence the allocation of the different competitive funds, such as the innovation fund, the Technology and Human Development Research for Industry Program (THRIP), and the funding programs of the National Research Foundation. Most universities doing agricultural research, as well as NGOs, submit applications to these funds.

Previously, funding for agricultural research in the provinces followed the priorities of the provinces' agricultural development programs. The establishment of the provincial departments of agriculture, and the associated restructuring initiatives, has led to a breakdown in this practice. ARC is now assisting provinces to redevelop their research capacity. There is very little coordination among the various players in setting research priorities in agriculture. Universities, ARC, and the PDAs rarely collaborate in research and often compete for research funds. The new NARF (described earlier) may improve this situation, but it has yet to secure funding for its initiatives in this regard (NDA 2001).

Sources of Funding for Agricultural R&D

The funds allocated to agricultural research in South Africa come from four sources. At the central-government level, the science budget is allocated by DST and various national government departments. Other national revenue sources include commodity trusts and levies from producer organizations and research funding from private-sector enterprises.[12] The increasing prominence of these enterprises in terms of research funding and the use of research services distinguishes South Africa's NARS from those of other African countries.

In addition to the structural changes in the agricultural R&D system, competitive bidding with other science councils for parliamentary grants (PGs) was introduced in 1997–98. Furthermore, it was decided that all external research contracts would be based on full cost recovery. This principle was not readily accepted by the various commodity organizations that fund research. As a compromise, a 50:50 cost-sharing arrangement was negotiated between the relevant institutes and commodity organizations.

Other major funders of agricultural research over the past five years have been various commodity trusts, which were established following market deregulation that involved the abolition of all marketing boards. The assets of these boards were transferred to trusts such as the Maize Trust, the Wool Trust, and the Red Meat Trust, and the returns from these assets are used to fund the activities of producer organizations and to fund agricultural research and the activities of the producer

Table 8.5 South Africa: Annual contribution by commodity organizations to agricultural research, 1999–2001

Source	Contribution (thousand rand)		
	1999	2000	2001
Trust contributions			
Animal	3,578.09	3,468.82	7,222.26
Crops	13,060.67	18,732.63	21,338.85
Horticulture	5,280.91	4,200.00	3,684.21
Subtotal	21,919.67	26,401.45	32,245.32
Levy income			
Crops	11,194.27	11,491.69	12,337.12
Horticulture	19,156.31	25,665.74	27,521.31
Subtotal	30,350.58	37,157.43	39,858.43
Total contributions from commodity organizations			
Animal	3,578.09	3,468.82	7,222.26
Crops	24,254.95	30,224.32	33,675.97
Horticulture	24,437.22	29,865.74	31,205.52
Total	52,270.25	63,558.88	72,103.75

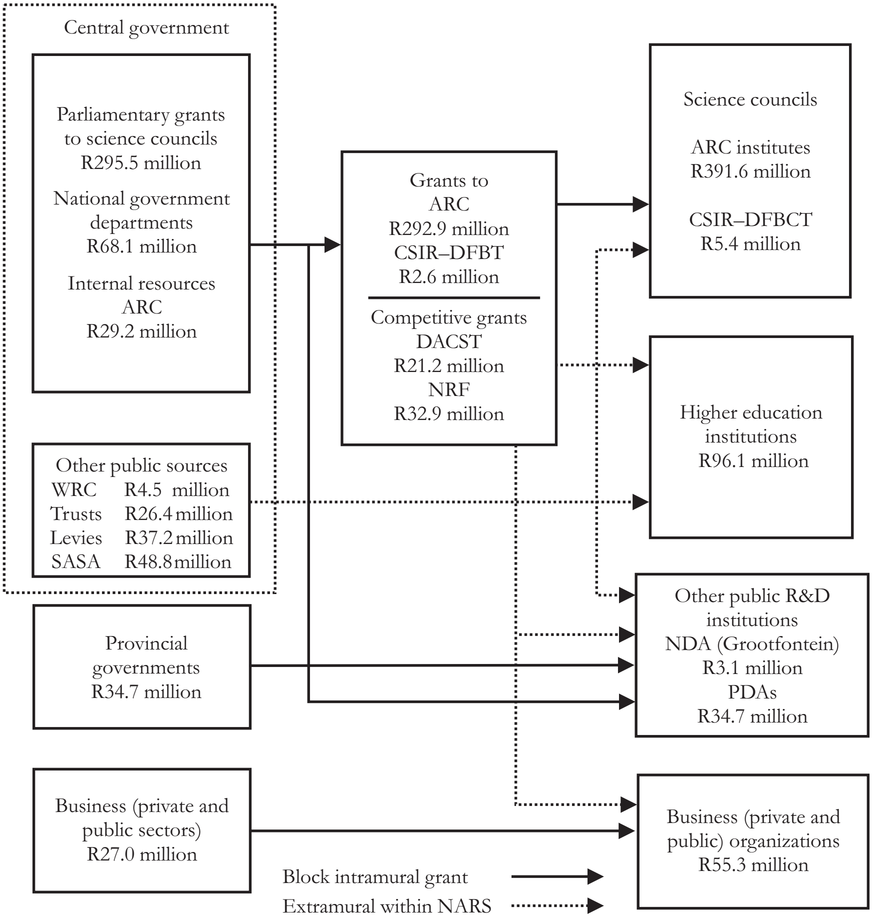
Source: Information provided by various trusts and commodity organizations (personal communications).

organizations. Table 8.5 provides an indication of the extent of research funding provided by commodity trusts and by statutory and voluntary levies managed by certain producer organizations since 1999.

Figure 8.2 shows the flow of funds within the South African NARS for 1999–2000. At the central-government level, the parliamentary grant from the science vote totaled R295.5 million, consisting of R292.9 million allocated to ARC and the balance allocated by the CSIR to its Division of Food, Biological, and Chemical Technologies (DFBCT). The various national departments allocated a further R68.1 million to agricultural research through performance and service contracts and competitive-bidding funds: the latter were mainly allocated through the THRIP programs and the innovation fund administered by the NRF, as well as the lead programs of DACST. An amount of R29.2 million is generated internally by ARC from its own resources.

Other public sources include R4.5 million allocated to agricultural research by the Water Research Commission. This represents 9.1 percent of the total research budget of the Water Research Commission, which receives its funding from a levy paid by all water use authorities. Funding from commodity and producer organizations supports research commissioned by the commodity trusts (R26.4 million) and levy income (R39.2 million for nonsugar commodities, R48.8 million for sugar). Funding from private enterprises comes mainly from input suppliers and

Figure 8.2 South Africa: Funding channels for agricultural R&D, 1999–2000



Sources: Compiled by authors from various sources, but mainly from Liebenberg, Beintema, and Kirsten 2004.

Notes: Data are nominal South African rand. Values may not tally exactly with those reported in other tables and figures because estimates of researcher expenditures were used elsewhere, and ARC corporate expenditures are included here.

WRC = Water Research Commission; SASA = South African Sugar Association.

agroprocessors, who outsource some research on a contract basis but also do in-house research. Monies allocated from these sources amounted to R27.0 million in 1999–2000.

ARC and the higher-education institutions dominate expenditure by research performers. Total expenditure in 1999–2000 is estimated at R586.2 million, of which R139.4 million came from nongovernment income sources. The total donor contribution to South African research is difficult to estimate but is assumed to be relatively small.

Agricultural research at the different faculties of agriculture is also funded from a range of sources. Commodity organizations and private companies generally support the major and longer-term projects; funds are also supplied to successful bidders under the innovation fund and the NRF. In addition, donor agencies have also recently provided some support for university research and postgraduate teaching initiatives.

Agricultural R&D Patterns

ARC is by far the largest provider of agricultural research in South Africa, employing 59.8 percent of the country's agricultural researchers in 1999 and accounting for 57.9 percent of total agricultural research expenditure—slightly more than ARC's 54 percent of total share at the time of its establishment (Roseboom et al. 1995). Universities have also shown strong growth in market share since 1992 (Table 8.6).

The situation appears to have changed significantly since 2000. The number of research staff at ARC dropped from 751 in 1992 to 682 (non-fte) in 2000 and 525 in April 2003. The biggest change in terms of qualifications was among Ph.D.- and M.Sc.-qualified researchers. Ph.D. numbers fell from 206 in 1997 to 179 in 2000. Of greater concern, ARC records at the end of April 2003 reflected only 144 staff with Ph.D.s employed at all the institutes (only 87 of whom were researchers), a decline of 35. The corresponding decline for research staff holding M.Sc. degrees is 41. By inference, 76 key research staff have left ARC since 2000, adding to the decline of the previous few years. This rapid decline is disturbing and could signal the demise of the agricultural research system in South Africa.

Ratios of support staff to scientists dropped from as high as 10.7:1 in 1992 to 3.9:1 in 2001. The ratio of technicians to researchers in ARC institutes fell from 1.7:1 in 1992 to 0.8:1 in 2001, indicating that research support is dwindling and that the remaining researchers and technicians must now spend more of their time on mundane duties. This trend has severe implications for ARC's capacity to maintain performance levels, which in turn will strongly affect the ability of South Africa's agricultural sector to support regional and local rural development initiatives.

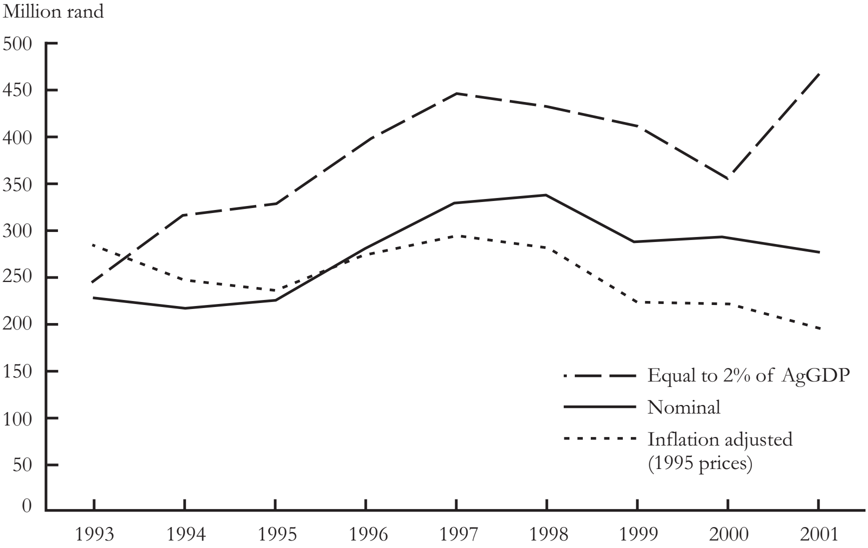
Table 8.6 South Africa: Composition of agricultural research expenditures and total number of researchers, 1999

	Spending			Percentage		
Type of agency	Million 1999 rand	Million 1999 international dollars	Researchers (fte)	Spending	Researchers	Number of agencies in sample
Government agencies						
Agricultural Research Council (ARC)	429.3	234.9	634.3	57.9	59.8	14
Other	123.4	67.5	168.4	16.7	15.9	12
Nonprofit institutions	56.1	30.7	56.0	7.6	5.3	3
Higher-education agencies	106.9	58.5	158.0	14.4	14.9	12
Business enterprises	25.2	13.8	44.5	3.4	4.2	9
Total	740.8	405.3	1,061.1	100	100	50

Sources: Recalculated from Liebenberg, Beintema, and Kirsten 2004. Deflators and PPP conversion from World Bank 2003.

Note: Expenditures for nine government agencies, two nonprofit institutions, and the higher-education agencies are estimates based on average expenditures per researcher for ARC; expenditures for three business enterprises are estimates based on average expenditures per researcher for the six business enterprises for which data were available. The 634 fte researchers listed include research technicians with degree qualifications. Rand converted to international dollars using purchasing power parity (PPP) indexes, which reflect the purchasing power of currencies by comparing prices across a broader range of goods and services than conventional exchange rates.

Figure 8.3 South Africa: The history of the parliamentary grant to the Agricultural Research Council, 1992–2002



Sources: Compiled by authors from NDA 2003; and ARC *Annual report,* 1993–2002.

The budgetary pressures resulting from the drop in the parliamentary grant could be the main reason behind the reductions in these ratios.

ARC funding provided by the government through the parliamentary grant system dropped from a peak of R337 million in 1997–98 to R262 million in 2001–02. The history of the parliamentary grant to ARC is well illustrated by the trend in Figure 8.3. The extent of the decline in funding is emphasized by the rapidly declining real value of the grant. By 2001–02, ARC received only 55 percent, in real terms, of the parliamentary grant it received in 1992. As a consequence, external income had to increase significantly to maintain overall spending at an estimated R450 million for 2001–02. Also shown in Figure 8.3 is ARC's level of baseline funding had it been maintained at 2 percent of AgGDP. Under the new Agricultural Sector Strategy (NDA 2001), it is envisioned that this target should be in the range of 3 percent.

Table 8.7 shows sources of ARC funding from 1998 to 2000, and relative shares for each year. External income for ARC came from commodity and producer organizations and donor funding. Income from commodity organizations contributed between 11.1 and 12.9 percent of ARC expenditure in the period 1998–2000. As shown in Figure 8.2, commodity organizations, as a whole, fund a total of 19.7

Table 8.7 South Africa: Agricultural Research Council funding sources, 1998–2000

	Total funding								
	Million rand			Million international dollars			Funding share		
Source	1998	1999	2000	1998	1999	2000	1998	1999	2000
Government	304.5	282.9	265.0	166.6	154.8	145.0	66.6	63.8	62.0
Bilateral donors	0.2	2.3	3.6	0.1	1.3	2.0	0.1	0.5	0.8
Multilateral donors	2.5	0.9	0.8	1.3	0.5	0.4	0.5	0.2	0.2
Producers and marketing boards	52.9	57.4	47.4	28.9	31.4	25.9	11.6	12.9	11.1
Public and private enterprises	50.3	62.5	60.9	27.5	34.2	33.3	11.0	14.1	14.2
Own income	32.1	29.2	44.2	17.5	16.0	24.2	7.0	6.6	10.3
Other	14.7	8.3	5.8	8.0	4.5	3.2	3.2	1.9	1.4
Total	457.2	443.5	427.7	249.9	242.7	234.0	100	100	100

Sources: Recalculated from Liebenberg, Beintema, and Kirsten 2004. Deflators and currency conversion from World Bank 2003.

Note: See Table 8.6 for details of international dollars.

percent (R112.4 million) of total R&D expenditure in South African agriculture. A few statutory levies were introduced by producer organizations as a way to raise funding for agricultural research, among other things. Voluntary levies are also used by some commodity groups, but income from these sources is highly unstable. Donor funding to ARC is growing, but access to it is severely limited by policy constraints. However, it seems that more donor funding has been flowing to universities for basic and applied agricultural research. Private funding to ARC is estimated at 14.2 percent of total ARC funding, and intramural research in many agricultural input firms has been growing because of the high returns on intellectual property rights (IPR) and patents in this industry. In addition, many private companies have awarded research contracts to universities. ARC's "own income" from royalties and IPR increased over the three years shown, from almost 7 percent to 10.3 percent.

Despite the growth in external funding, the government (through the parliamentary grant and a range of contracts) remains the largest single source of funding (around 62 percent) for ARC. However, the dual accountability of ARC institute directors to public and private funders is becoming a serious issue in resource-allocation decisions.

Institutional Accountability Mechanisms

Science Councils report both to the line ministry and to the Minister of Arts, Culture, Science, and Technology on their annual performance. For PDAs, the line of reporting is under the various provincial legislatures, with coordination through

ITCA. Universities report to DNE, coordinated by a committee of the heads of the agriculture faculties. Given the strong degree of autonomy of the various research service providers, no single authority has control over the activities of all the country's research providers. This situation reinforced the need for establishing the NARF, which was recommended as early as 1996 but only eventuated in 2002. Although recognized and funded by the NDA, the NARF is still battling to become fully operational.

The promulgation of the Public Finance and Management Act in 1999 (Act 1 of 1999) has led to a legal requirement on public entities (parastatals) to report to Parliament on their service delivery according to a set of formal, predetermined objectives and performance indicators. DACST has taken the lead in harmonizing the diverse basis of reporting from the various science councils to authorities such as NACI and Parliament.

Using a "balanced scorecard" technique, a set of 25 indicator areas has been identified in the areas of finance, stakeholder satisfaction, internal business organization, and internal learning and growth. To include the performance of delivery on equity legislation, a fifth reporting category was identified and included: human resources and transformation. Each science council developed its own set of indicators for measuring and reporting on performance under each of these categories (where applicable). Steps are being implemented to develop greater uniformity in the measures used by the various science councils to facilitate intercouncil comparisons and reduce the administrative burden of reporting.

In 1995, ARC established a small impact-assessment unit, the Group for Development Impact Analysis, to introduce social sciences research into ARC's activities. Being small, the unit was located centrally and provides services to institutes throughout the country. One of the unit's first initiatives was to contract a series of aggregate rate-of-return studies (Table 8.8). Results show that on average, the social rate of return on the investment in agricultural research has been positive and fairly high. A number of cost–benefit impact-assessment case studies have also been done.

Further, the unit actively participated in project feasibility studies and the training of researchers and research managers in project-level monitoring and evaluation techniques. A further area of activity since 1998 involved support to corporate management in policy advice and planning. Although, to date, formal mechanisms for priority setting have been restricted to the institute level, there is a growing need to expand them to the corporate level within ARC. Stakeholders requested this change in March 2001. In the seven years since its establishment, the demand for the unit's services and appreciation of the importance of the information it generates have grown exponentially, although trends in public funding to ARC have

Table 8.8 South Africa: Rate-of-return studies on the impact of agricultural research by level of aggregation

Level	Commodity	Method	Period	Rate of return (percent)	References
National	Research and development	Two-stage decomposition	1947–91	60–65	Thirtle and van Zyl 1994
	Extension			28–35	
	Research and development	Profit function	1947–92	44	Arnade et al. 1996; Khatri et al. 1995
	–Short-term				
	–Long-term			58–113	Arnade et al. 1996; Khatri et al. 1995
	Extension			Very low	Arnade et al. 1996; Khatri et al. 1995
Agricultural subsectors	Field crops	Profit function	1947–92	30	Thirtle et al. 1998
	Horticulture		1947–92	100	Thirtle et al. 1998
	Livestock		1947–92	5	Thirtle et al. 1998
Enterprises	Animal health	Production function	1947–82	>36	Thirtle et al. 1998
	Animal production	Supply response	1947–94	11–16	Thirtle et al. 1998
	Bananas	Supply, area, and yield	1953–95	50	Thirtle et al. 1998
	Deciduous fruit	Supply response	1965–94	78	Thirtle et al. 1998
	Groundnuts	Yield changes	1968–95	50	Thirtle et al. 1998
	Maize	Error-correction model	1950–95	29–39	Thirtle et al. 1998
	Sorghum	Error-correction model	1950–95	50–63	Thirtle et al. 1998
	Sweet potatoes	Supply response	1952–94	21	Thirtle et al. 1998
	Tobacco	Supply, price lags	1965–95	50–53	Thirtle et al. 1998
	Wheat	Error-correction model	1950–95	26–34	Thirtle et al. 1998
	Wine grapes	Error-correction model	1987–96	40–60	Townsend and van Zyl 1998
Research programs	Dairy, beef, mutton, and pork performance, and progeny testing schemes	Economic surplus	1970–96	2–54	Mokoena, Townsend, and Kirsten 1999
	Cover-crop management	Yield and residual	1987–96	44	Thirtle et al. 1998
	Lachenalia research and development[a]	Economic surplus	1965–2015	7–12	Marasas et al. 1998
	Proteaceae research and development[a]	Economic surplus	1974–2005	8–12	Wessels et al. 1998
	Russian wheat aphid integrated-control program[a]	Economic surplus	1980–2005	22–28	Marasas 1999

Source: Compiled by authors.

[a] Preliminary results of these studies were published as reports by the Agricultural Research Council and the Southern African Centre for Cooperation in Agricultural and Natural Resources Research and Training.

stymied efforts to expand the unit by placing personnel in the institutes. Unit-facilitated policy workshops disseminating the information developed have succeeded in building understanding among key NARS stakeholders regarding the future direction of agricultural research. In line with the exodus of researchers from the ARC, the staffing of the unit has fallen from 11 in 2000 to 2 in April 2003.

The Provision of Agricultural R&D Services

The dominance of ARC in South African agricultural research is evident through an overview of its various research providers (Table 8.9).

Government and local agencies. The national government has introduced a number of programs to direct resources toward priority initiatives, responding to pressure to fulfill its growth and development strategy and to deal with the difficulties experienced by provincial research agencies in adapting to their new mandate. These changes have directly affected ARC's priorities and activities. ARC was continuously urged to adjust its operations in line with the seven presidential imperative programs (PIPs), one of which focuses on rural development. Government departments were clustered around these PIPs according to their potential ability to deliver on the initiatives from their existing budgets. Meetings between the minister of agriculture and the provincial ministers (MINMEC) have also identified five-year priorities for agriculture that closely relate to the PIPs. Since November 2001, the new sector strategy for agriculture has formed the basis for policy and service-provision alignment (NDA 2001). Producer and commodity organizations often enter partnerships with public-sector R&D service providers such as ARC. The greatest successes have come when ARC has taken the lead in project management, and the universities, provincial departments, producer organizations, and farmers have each contributed financially or in kind.

Universities. Faculties of agriculture at the larger universities are in a much better position to maintain capacity under the current circumstances. Core funding for universities is provided by the National Department of Education (NDE) and primarily underwrites salaries and overhead. Direct research costs are usually funded through research contracts with producer organizations, private companies, and some international donors. In addition, researchers at universities compete for research funds such as the innovation fund and annual grant funding for researchers from the NRF. The large variety of funding sources makes it difficult to develop a clear picture of spending on agricultural R&D by universities. There is growing concern that universities are venturing into applied research, thereby usurping potential

Table 8.9 South Africa: Agricultural research expenditure by institutional category, 1992–2000

Institution	1992	1993	1994	1995	1996	1997	1998	1999	2000
Million 1999 rand									
Government agencies									
Agricultural Research Council (ARC)	422.9	414.2	404.4	480.3	494.1	483.4	519.5	452.9	429.3
Other	126.9	135.0	126.5	138.3	133.5	129.5	130.2	116.3	123.4
Subtotal	549.8	549.1	530.9	618.6	627.6	612.9	649.7	569.3	552.6
Nonprofit institutions	60.6	55.0	49.3	51.6	53.1	50.9	54.2	56.7	56.1
Higher-education agencies	72.8	78.9	77.0	85.8	82.8	80.2	101.4	101.7	106.9
Business enterprises	27.2	27.1	27.6	28.7	27.7	26.0	26.6	21.3	25.2
Public total	683.2	683.1	657.2	755.9	763.5	744.0	805.3	727.7	715.6
Total	710.4	710.1	684.8	784.6	791.2	770.0	831.9	749.0	740.8
Million 1999 international dollars									
Government agencies									
Agricultural Research Council (ARC)	231.4	226.6	221.2	262.8	270.3	264.5	284.2	247.8	234.9
Other	69.4	73.8	69.2	75.7	73.0	70.8	71.3	63.7	67.5
Subtotal	300.8	300.4	290.5	338.5	343.4	335.3	355.5	311.5	302.3
Nonprofit institutions	33.2	30.1	27.0	28.2	29.1	27.9	29.7	31.0	30.7
Higher-education agencies	39.9	43.2	42.1	46.9	45.3	43.9	55.5	55.6	58.5
Business enterprises	14.9	14.8	15.1	15.7	15.1	14.2	14.6	11.6	13.8
Public total	373.8	373.7	359.5	413.6	417.7	407.0	440.6	398.1	391.5
Total	388.7	388.5	374.6	429.3	432.9	421.3	455.2	409.8	405.3

Sources: Recalculated from Liebenberg, Beintema, and Kirsten 2004. Deflators and currency conversion from World Bank 2003.

Notes: Expenditures for nine government agencies, two nonprofit institutions, and the higher-education institutions are estimates based on average expenditures per researcher for ARC; expenditures for three business enterprises are estimates based on average expenditures per researcher for the six business enterprises for which data were available. The 634 FTE researchers listed include research technicians with degree qualifications. See Table 8.6 for details of international dollars.

projects from ARC. This shift is partly a result of commodity organizations either perceiving that ARC's capacity is declining or being attracted by lower rates charged by universities.

International agencies. The CGIAR system has provided useful support and information since 1994. There has been little direct involvement in South African agricultural research, however, apart from a few donor-driven projects. Involvement is increasing, and the establishment of a regional office for the International Water Management Institute (IWMI) in Pretoria is an example of this growing trend. IWMI works in close collaboration with ARC, the government, and universities on issues related to the rehabilitation of irrigation schemes, the development of an irrigation policy, and the development of irrigation scheme management.

Regional R&D organizations, such as the Southern African Centre for Cooperation in Agricultural and Natural Resources Research and Training (SACCAR), are becoming more important. SACCAR, under the auspices of the SADC, used to allocate certain research initiatives to specific SADC member states. Following the restructuring of SADC, SACCAR now takes greater direct responsibility for research. Member states no longer have the sole responsibility to fund and manage these initiatives, with only the review and consultation of the SACCAR council and its subsidiary technical committees. ARC used to represent South Africa's R&D interests at SACCAR. Whereas universities still have representation, NDA has now taken over this responsibility, for all foreign representation and liaison of agricultural R&D.

The World Bank–funded Special Program on African Agricultural Research (SPAAR) has also been changed to a more permanent initiative with the creation of the Forum on Agricultural Research in Africa (FARA) in Addis Ababa in April 2001. The intention is to provide a forum for harmonizing agricultural R&D in Africa through the initiatives of the three regional agricultural research organizations in Sub-Saharan Africa: SACCAR, the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA), and the Western and Central African Council for Agricultural Research and Development (CORAF). This arrangement allows Africa to take greater ownership of its R&D. The Mbeki government is also taking the lead in implementing the New Partnership for Africa's Development (NEPAD), which has a strong focus on agricultural development.

Lessons Learned and Future Challenges

The changes that began in the early 1970s led to an increasingly fragmented agricultural research system, and efforts to integrate the system's components and improve overall efficiency are incomplete. In the process of reforming the national agricultural research system in South Africa, several lessons have been learned.

It is important to maintain continuity in NARS leadership and for those leaders to have direct communication with institutional leaders. Commitment to goals, and the initiatives implemented to achieve them, is imperative, as is the capacity to monitor and adjust to changes. Ad hoc, uncoordinated responses to change within such a complex system as South Africa's NARS is, perhaps, the most important cause of fragmentation and duplication of effort.

Stakeholders must have access to appropriate information and analyses when making decisions, and their roles and responsibilities must be clearly established and understood. Memoranda of understanding or contracts can be used to communicate and clarify this information. Throughout, the focus should be on the coordination, content, and evaluation of programs.

A crucial factor is the policy environment that supports mobilizing funds, developing and maintaining the human-resource capacities of the system, and facilitating communication. This is one of the most neglected areas from the viewpoint of agricultural R&D policy in South Africa. These issues are emphasized only periodically; consistent effort by a critical mass of policy researchers is needed, as is an effective, world-class agricultural science fraternity to encourage greater numbers of students to train in the agricultural sciences. A substantial scholarship program for students is urgently needed to redress the substantial loss of qualified scientists from South Africa.

The increased role of private organizations and commodity trusts in funding the ARC illustrates the general experience of public research entities that increasingly rely on nonpublic sources of funding. Commodity trusts have shown a strong willingness and ability to increase their contributions. However, the amount of funding from these sources fluctuates markedly depending on industry market conditions. In South Africa it is also susceptible to the vagaries of sectoral politics and the failure of public entities to allow private funders of public research to secure intellectual property rights on research output. If public-research service providers fail to reach mutually acceptable positions with private funders on intellectual property rights issues (and, relatedly, the allocation of research resources), they may well be unable to ensure a stable flow of adequate funding and retain competent staff.

The establishment of the NARF in 2002 marked the beginning of a new phase in South Africa's agricultural R&D. The NARF could be critical in securing not only the future of agricultural research in South Africa but also the sustained international competitiveness and prosperity of agriculture in South and southern Africa. Unfortunately, since its establishment, the NARF has failed to become operative as a policy advisory body or to formulate appropriate policy responses to the issues listed here. ARC's experience over the past 10 years could be invaluable in the planning and implementation of a much more effective NARS into the future.

Appendix Table 8A.1 South Africa: Structure of the agricultural research system, 2000

Institutional category	Supervising agency	Executing agency	Research focus	Number of staffed research sites	Number of researchers in 2000 (1993 figures in parentheses)
Government	Agricultural Research Council (ARC)	Grain Crops Institute (GCI)	Groundnuts, sunflower, sorghum, soybeans, maize, dry beans, lupines, and cowpeas	1	37 (84)
		Small Grains Institute (SGI)	Wheat, oats, barley	5	27 (29)
		Institute for Industrial Crops (IIC)	Cotton, tobacco, hemp, flax	1	17 (25)
		Vegetable and Ornamental Plant Institute (VOPI)	Vegetables and ornamental plants	1	21 (55)
		Institute for Tropical and Subtropical Crops (ITSC)	Tropical and subtropical fruits	9	37 (41)
		Infruitech-Nietvoorbij	Pome and stone fruit, viticulture, and enology; breeding, physiology, horticulture; biotechnology; postharvest technology	4	139 (82)
		Rangeland and Forage Institute (RFI)	Grassland and forage	1	32 (40)
		Animal Improvement Institute (AII)	Animal production and improvement	1	43 (52)
		Animal Nutrition and Products Institute (ANPI)	Animal nutrition; farming systems; animal products; food security; small, medium, and micro-enterprise development	2	32 (66)
		Onderstepoort Veterinary Institute (OVI)	Animal health	1	61 (78)
		Plant Protection Research Institute (PPRI)	Plant protection	8	103 (105)
		Institute for Agricultural Engineering (IAE)	Agricultural engineering, wine technology	2	20 (23)[a]
		Institute for Soil, Climate, and Water (ICSW)	Soil science, climatology, hydrology, water	1	76 (62)
		Development Impact Assessment Unit	Socioeconomic studies	1	8 (–)
		Biometrics Unit	Biometrics	1	12 (30)
Government	National Department of Agriculture	Grootfontein Agricultural Development Institute	Production and resource utilization technology	1	7 (23)
	Free State Department of Agriculture	Glen	Crops, livestock, pastures, natural resources; production technology	4	13 (26)
	Northwest Department of Agriculture	Potchefstroom	Crops, livestock natural resources; production technology	5	23 (41)

	Kwazulu-Natal Department of Agriculture	Cedara	Crops, livestock, natural resources	6	44 (18)
	Mpumalang Department of Agriculture	Nelspruit	Animal science, crops science, natural resources	3	12 (–)
	Western Cape Department of Agriculture	Elsenburg	Animal science, crops science, natural resources	7	59 (31)
	Northern Cape Department of Agriculture	Upington	Animal and crop production and resource utilization	2	6 (–)
	Council for Scientific and Industrial Research (CSIR)	Bio/Chemtek	Food; biological and chemical technologies	2	15 (–)
Academic	University of Stellenbosch	Faculty of Agriculture and Forestry Sciences	Agriculture and forestry	1	94 (95)
	University of Pretoria	Faculty of Natural and Agricultural Sciences	Agriculture and natural sciences	1	108 (59)
		Faculty of Veterinary Science	Animal health	1	114 (77)
	University of Natal	Faculty of Science and Agriculture	Agriculture and natural sciences	1	31 (72)
	University of the Free State	Natural and Agricultural Sciences	Agricultural and natural sciences	1	54 (52)
	University of the North	Faculty of Sciences, Health, and Agriculture	Agriculture and natural sciences	1	(14)[b]
	University of Fort Hare	Faculty of Agriculture	Agriculture	11	(37)[b]
		Agricultural and Rural Development Institute	Agriculture and rural development		
	University of North West	Faculty of Agriculture	Agriculture		
	University of Zululand	School of Agriculture	Agriculture		
	University of Venda	School of Agriculture	Agriculture		32
Semipublic	South African Sugar Association (SASA)	SASA experiment station	Sugar	1	31 (33)
Private	Capespan	Capespan Technology Development	Deciduous fruit postharvest research	1	17
	Intervet	Malelane Research Unit	Veterinary products	1	4
	Hortech	Hortech	Horticulture, entomology, pathology	1	9
	Kynoch	Kynoch Agronomy Research	Fertilizer, agronomy	1	4
	GrainSA	Grain SA R&D unit	Socioeconomics, farming systems	1	5
	Dow Agri	Dow Agrosciences	Crop pest and disease control	1	3
	Sugar Milling Research Institute		Sugar processing	1	18
	Epol	Technical Department	Animal feed	1	1

Source: Compiled by authors from Liebenberg, Beintema, and Kirsten 2004.

Note: Staffing numbers here do not refer to full-time equivalents and should thus not be compared with those of ARC, where researchers spend almost 100 percent of their time on research. The institutions included here indicated in the 2001 ASTI survey that they were engaged in agricultural research. A dash within parentheses indicates that agencies did not exist in 1993.

[a] 1995 estimate.

[b] No response to 2000 survey.

Notes

1. On May 23, 2002, the first steering committee of NARF was elected by the stakeholders. The committee has developed a number of project proposals on NARS policy issues.

2. Given a poverty line of R352 monthly household expenditure per adult equivalent (May 2000).

3. People not formally employed, which typically includes those engaged in subsistence activities enterprises, casual labor, street traders, and hawking.

4. The DBSA (2000, p. 193) used the following definition for unemployment: persons 15 years of age and older who, during the reference week, were not in paid work or self-employment, were available for paid work or self-employment, took specific steps during the four weeks preceding the interview to find paid work or self-employment, or had the desire to work and would be available to take up a suitable job were one offered.

5. In June 2002 the South African rand was trading at R10.05 to the U.S. dollar, and the World Bank purchasing parity exchange rate was R2.2 to the U.S. dollar.

6. This section draws largely from a paper by van Zyl, Vink, and Kirsten (2001) prepared for the *Journal for International Development.* See Vink 2000 for a review of recent South African literature on the process and results of deregulation in agriculture since the early 1980s.

7. Until the 1990s, the policy of the Department of Agriculture was to negotiate with only one representative body of farmers—the South African Agricultural Union (SAAU), now known as Agriculture South Africa (Agri-SA).

8. A group of countries, including Australia, New Zealand, South Africa, Brazil, and Argentina, that support the principle of free trade in agricultural commodities.

9. This refers to the amount authorized annually by the national government for all the science and technology initiatives it funds.

10. For more details, see Roseboom et al. 1995.

11. Following the 1983 referendum, a three-chamber parliament was established, but all government affairs were still classified according to race, with "own" affairs and "general" affairs departments.

12. Levies can be voluntary or statutory, the latter having been introduced under the Agricultural Marketing Act. The rate varies from commodity to commodity, but the National Agricultural Marketing Council prescribes that it should not exceed 5 percent of the guideline price.

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