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CONTENTS

Introduction 1

Agricultural Growth and Productivity Developments 2

National Agricultural Research 5

A Brief History of Public Agricultural Research 8

Private Research 10

Human Capital in Research 11

International Agricultural Research . . 13

Political and Financial Support for Agricultural Research 17

Emerging Issues 21

Sustainability 22

Closing Comments 24

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INTRODUCTION

As we approach the end of the 20th century, policymakers are having to contend with unprecedentedly rapid changes in the market for agricultural science and technology services. In less-developed countries the rapid expansion of agricultural research capacity experienced during the 1960s and 1970s slowed considerably in the 1980s. Particularly in debt-ridden regions like sub-Saharan Africa and Latin America & Caribbean, investment in agricultural research stagnated or even declined. In addition, the level of development aid to less-developed countries stalled during the 1980s, while the small but significant share that was channeled to agricultural research has been threatened by other demands. A reversal of these trends is unlikely in the near future and resources for public agricultural research in less-developed countries could well tighten even further in the coming years. In the more-developed countries, public support for agricultural research is under close review and there is a strong tendency to have those who most directly benefit from research pick up at least part of the bill. Moreover, agricultural surpluses, declining agricultural prices, and a continuing contraction in farm numbers in many of the more-developed countries have led to populist calls for a moratorium on further public investment in agricultural research.

Against this backdrop of fiscal stringency, the demands placed on national, and indeed international, research systems are intensifying. In addition to the traditional emphasis on stimulating productivity growth within agriculture, many of these systems are being called upon to broaden their research agendas and give greater attention to concerns of environmental degradation and resource management. The international system is also restructuring its research portfolio with regard to forestry, fisheries, and vegetable research in addition to its traditional emphasis on basic food crops and livestock. These changes raise major policy issues that are yet to be resolved about the appropriate division of labor and problem focus between the national, regional, and international centers.

Furthermore, the modern biotechnologies based on recombinant DNA, monoclonal antibodies, and new cell- and tissue-culture techniques are just beginning, and no doubt will continue, to fundamentally reshape the science of agriculture well into the 21st century. When taken in conjunction with the increasing propensity of governments to enact and enforce legislation on intellectual property rights (including plant variety protection acts), these new technologies raise a further set of policy concerns related to the optimal division of labor and effort between publicly versus privately executed research.

Within the context of these issues, what follows is an attempt to illustrate what is actually happening in the world of agricultural research and to help move the policy dialogue beyond merely qualitative impressions toward a process that is underpinned with a set of basic data and quantitative indicators.

Note:

Currency units: The monetary values throughout this booklet have been expressed in constant 1980 PPP dollars. PPP stands for *purchasing power parity* and represents a synthetic exchange rate that attempts to reflect the purchasing power of a currency. Monetary values in current local currency were first deflated to base-year 1980 with a local (GDP) deflator and then converted into constant 1980 dollars using 1980 PPP exchange rates.

Country coverage: The global comparisons presented in this booklet do not include the former USSR, Eastern Europe, Cuba, Vietnam, Cambodia, the Republic of South Africa, and a number of very small countries for which no data were available.

Agricultural Growth and Productivity Developments

The last two decades have seen impressive levels of growth in the world's economy. During that period, the per capita gross domestic product (GDP) rose by around 50% despite a sustained increase in the world's population. In the nonagricultural sector, output increased faster than it did in agriculture, where growth was also more erratic.

Despite the overall growth in the global economy, and although total and per capita output increased faster in less-developed countries as a whole than in the more-developed countries, the per capita income gap between the rich and the poor countries has widened in real terms. Among the less-developed regions themselves, there have also been significant differences in economic growth rates, with sub-Saharan Africa and China representing the extremes in economic performance in the recent past. In sub-Saharan Africa the population grew faster and the GDP grew more slowly than anywhere else, while in China the opposite occurred.

Table 1: *Regional Shares of Agricultural GDP, Population, and Land, 1981-85 Average*

Region	Agricultural GDP	Agricultural Population	Agricultural Land[a]
	%	%	%
Sub-Saharan Africa (42)[b]	7	14	20
China	22	35	12
Asia & Pacific, excl. China (21)	31	39	8
Latin America & Caribbean (32)	11	6	20
West Asia & North Africa (18)	7	4	8
Less-Developed Countries (114)	78	98	68
More-Developed Countries (22)	22	2	32
Total Sample (136)	100	100	100

[a] Agricultural land comprises arable land, permanently cropped land, and permanent pastures.
[b] Bracketed figures indicate the number of countries in regional totals.

In the period 1981-85, less-developed countries had only a 36% share in global GDP although they support 82% of the world's population. Considering agriculture separately, the differences were even more pronounced. Of the world's agricultural population, 98% live in less-developed countries, but with 68% of the world's farmland they produced just 78% of total agricultural GDP. So 2% of the world's agricultural population in more-developed countries produced 22% of global agricultural GDP (table 1).

Nor did all less-developed regions share equally in the growth in agricultural output in the last two decades. In 1981-85 the Asia & Pacific region plus China produced 53% of global agricultural GDP, with 23% of the world's agricultural land and 74% of the labor force. Sub-Saharan Africa has the same share of the world's farmland but produced only one-fifth of Asia's output.

Although the proportion of the total population that is involved in agriculture in most less-developed countries is declining, the agricultural labor force in those countries still rose by 35% between 1961-85, with the Asia & Pacific region accounting for 81% of that amount. In more-developed countries the agricultural labor force shrank by almost half, but the farmland in use remained stable while the application of output-enhancing inputs, such as fertilizers and machinery, increased.

Nevertheless, agriculture still accounts for a major share of total GDP in many less-developed countries, and it is likely that the failure to develop this sector accounts, at least in part, for the widening rift in incomes with the industrialized world.

Much of the growth in agricultural production during the past decades came about through the impact of the Green Revolution. Its immense contribution to feeding a rapidly growing world population is not in doubt, but there is still some dispute about the effects of these technologies on income distribution. Early studies suggested the new tech-

nologies had unfairly benefitted larger farmers at the expense of small-scale producers. More recent studies have questioned this and have suggested that as time has elapsed, more of the benefits have been captured by the poorer sections of society, particularly as consumers of cheap food. A major concern, however, remains the fact that the Green Revolution technologies are most effective under favorable conditions and that they have largely by-passed farmers in marginal areas.

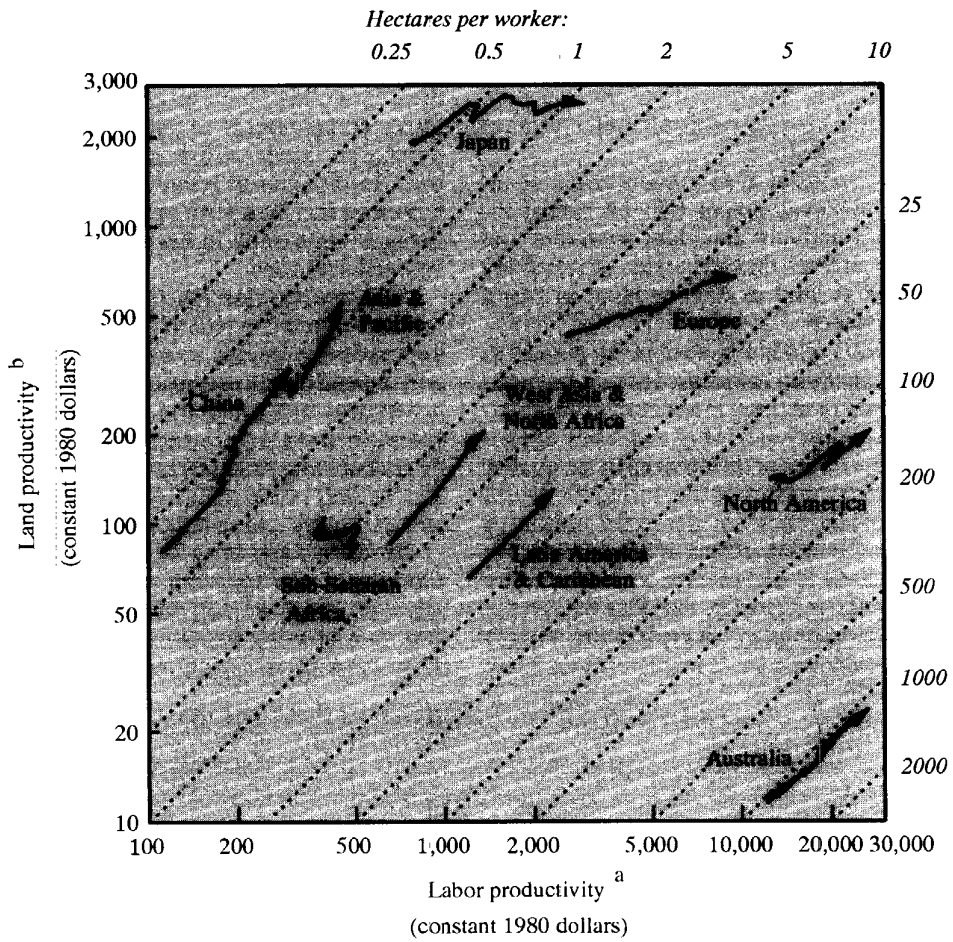
Developments in Agricultural Productivity

Figure 1 plots the relative productivity of labor and land and their changes over time for 73 countries between 1961 and 1985. The countries in the sample are divided into six regions and three countries. The dark arrows indicate how output per worker and per hectare developed over the period. The diagonals indicate constant factor ratios, so that when an arrow crosses a diagonal from left to right, it indicates that the number of hectares in use per agricultural worker increased; also, the longer an arrow, the greater the percentage change in productivity.

Levels of output per worker were higher in more-developed countries than in less-developed countries, with the lowest output per worker recorded in China. The highest output per hectare occurred in Asia (particularly Japan) and Europe, with the lowest in Australia.

There were significant differences between regions in the directions that agricultural productivity developed. In Japan, Europe, and the United States, output per worker increased much faster than output per hectare in conjunction with falling numbers of agricultural workers and relative stability in the area of land used in agriculture. On the other hand, in China and Asia & Pacific, the labor intensity in agriculture increased — these regions employ the highest number of workers per hectare. The pattern of agricultural growth was dominated by increased output per hectare rather than increases in output per

Figure 1: *Productivity paths, 1961-1985*



Note: Land and labor productivities measured in natural log scale.

[a] Labor productivity measured as AgGDP per economically active agricultural population.
[b] Land productivity measured as AgGDP per hectare agricultural land.

unit of labor. In West Asia & North Africa and Latin America & Caribbean, the ratio of land to labor remained fairly steady and productivity gains from both factors have been roughly equal.

The pattern of growth in sub-Saharan Africa is clearly distinguishable from other regions. Labor productivity declined and output per hectare stagnated, contrasting sharply with all other regions where growth was positive.

The results would seem to confirm that a country's agricultural development will be biased towards using its relatively abundant resources and saving on the resources that are scarce or relatively expensive, such as land in Asia or labor in North America, for instance.

Figure 1 gives a general picture of the pattern of agricultural productivity in the last decades but must be used cautiously in making international comparisons. The measures used for land and labor are not adjusted to take account of differences in the quality of the input or their intensity of use during the period reviewed. So the land measure is the total number of hectares in agriculture regardless of its quality or the improvements made to it over time, for example, by irrigation or terracing. Equally, the labor measure is the total population engaged in agriculture in each region with no allowance made for differences in the quality of the labor force or actual hours worked. It has been established, for instance, that educational standards have a major influence on the productivity of a labor force.

In addition, measurements of productivity based only on land and labor present an incomplete picture of productivity developments because they ignore the role of other inputs that can be used as substitutes for or complements to land and labor. The use of purchased inputs differs markedly between countries. In the poorest less-developed countries, they represent less than 10% of the value of final output, rising to about 50% in the most advanced more-developed countries.

Just as past increases in agricultural production can be attributed in part to research-induced technological developments, so agriculture's future growth will depend on current research. The level of public investment in agricultural research will in turn be determined to a significant degree by how successful it is in boosting production and productivity, as well as reaching other social goals and objectives that include equity and sustainability concerns.

Since time lags in agricultural research and in the adoption of new agricultural technologies tend to be relatively long, we will concentrate in the next section on reviewing trends rather than on a snapshot of investments in agricultural research.

National Agricultural Research

The differences in patterns of agricultural growth just identified are in large part the result of national differences in factors of production and environmental endowments as well as in the policies adopted towards agriculture and, more specifically, agricultural research.

What follows is a comparative assessment of the evolution and current status of national agricultural research systems (NARSs) using the most recently compiled figures on expenditures, numbers of researchers, and the like.

Investment Trends

For two decades, up to the mid-1980s, global investment in public agricultural research increased substantially. Between 1961-65 and 1981-85, the total number of public-sector agricultural researchers grew at an average annual rate of 4.1%. The number of researchers in less-developed countries increased by 7.1% a year, just over four times the annual rate in more-developed countries (table 2).

In the period 1981-85, the less-developed countries employed 58% of the world's agricultural researchers, compared with 33% in 1961-65.

Annual growth rates in research investment in less-developed countries have slowed during the 1980s, most noticeably in sub-Saharan Africa and Latin America & Caribbean, both of which have been struggling to contain soaring international debts. Nevertheless, spending on agricultural research increased faster in less-developed than in more-developed countries over the past two decades, so the less-developed countries' share of total expenditure on research rose to 43% in 1981-85 from 33% in 1961-65 (figure 2).

Of the less-developed regions, only in Asia & Pacific did the annual growth in research expenditure exceed the annual increase in researchers. In more-developed countries, on the other hand, spending on research increased twice as fast as the number of researchers.

Expenditures per Researcher

Average spending per researcher in less-developed countries has been falling since the early 1970s. In 1981-85 it was actually lower in real terms than in 1961-65. In more-developed countries meanwhile, spending per researcher has been rising steadily and the emphasis has consistently been towards greater investment in human capital within the NARS.

One reason for the relatively lower spending per researcher in less-developed countries is that, of late, the rapidly expanding university systems in these countries have produced substantially more graduates than previously. Many governments in less-de-

Figure 2: *Regional shares in global agricultural research personnel and expenditures, 1981-85 average*

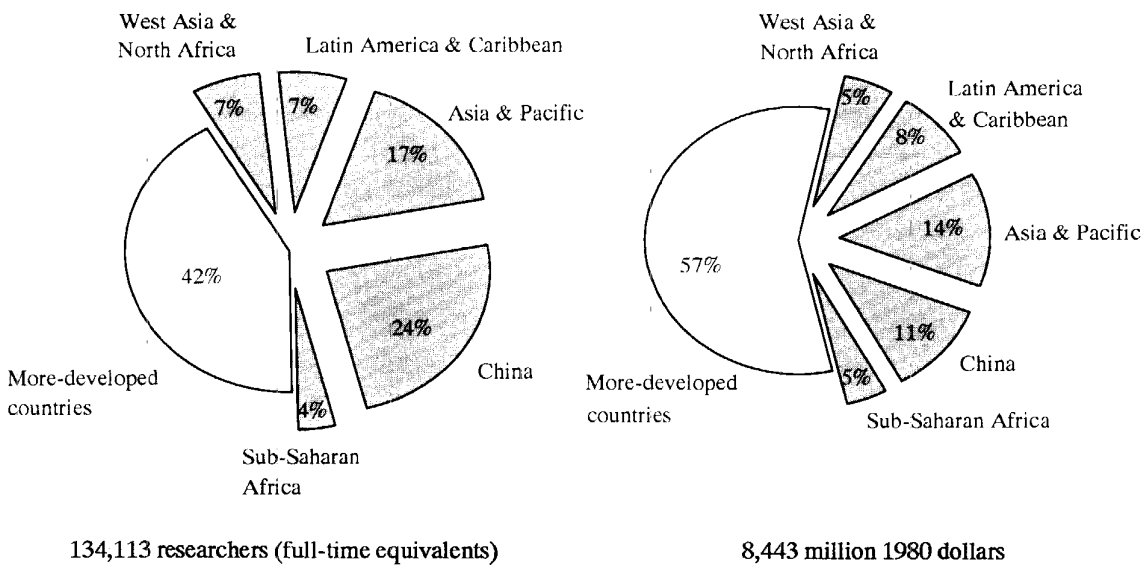


Table 2: *Annual Agricultural Research Personnel and Expenditures, Regional Totals*

Region	1961-65	1971-75	1981-85	Growth rate[a]
	Agricultural research personnel (full-time equivalents)			%
Sub-Saharan Africa (43)[b]	1,323	2,416	4,941	6.8
China	6,966	11,563	32,224	8.0
Asia & Pacific, excl. China (28)	6,641	12,439	22,576	6.3
Latin America & Caribbean (38)	2,666	5,840	9,000	6.3
West Asia & North Africa (20)	2,157	4,746	8,995	7.4
Less-Developed Countries (130)	19,753	37,004	77,737	7.1
More-Developed Countries (22)	40,395	48,123	56,376	1.7
Total (152)	60,148	85,126	134,113	4.1
	Agricultural research expenditures (millions 1980 dollars)			
Sub-Saharan Africa (43)[b]	149.5	276.9	372.3	4.7
China	271.4	485.4	933.7	6.4
Asia & Pacific, excl. China (28)	316.7	651.5	1,159.6	6.7
Latin America & Caribbean (38)	229.1	486.6	708.8	5.8
West Asia & North Africa (20)	126.9	300.8	455.4	6.6
Less-Developed Countries (130)	1,093.6	2,201.0	3,629.8	6.2
More-Developed Countries (22)	2,190.7	3,726.3	4,812.9	4.0
Total (152)	3,284.3	5,927.3	8,442.7	4.8

Note: Totals may not add up exactly because of rounding.

[a] Compound annual average growth rate between 1961-65 and 1981-85.

veloped countries require that public bodies, including research agencies, employ local graduates but then fail to provide adequate matching funds.

In China and the Asia & Pacific region, expenditure per researcher has always been lower than in other less-developed regions. This is partly because relative prices for labor are lower, which induces a substitution of labor for other inputs in the system. But it is also because they have predominantly larger research systems that may well be able to realize economies of scale and scope.

In sub-Saharan Africa, expenditure per researcher has for a long time been higher than in other regions. During the 1960s, the NARSs in this region continued to be heavily staffed by relatively expensive expatriates from the former colonial powers. The poor quality of Africa's infrastucture and the need to import nearly all equipment also drive up the research costs in this region. Although still higher than in most other less-developed regions, spending per researcher in sub-Saharan Africa is falling, in part a reflection of the fact that expatriate researchers are increasingly being replaced by less expensive local research staff.

Commodity Orientation

In less-developed countries, agricultural research is directed predominantly at crops. Roughly two-thirds of all agricultural researchers are engaged in work related to crops. For the remainder, 19% are engaged in livestock research, 7% in forestry research, and 6% in fisheries research (table 3).

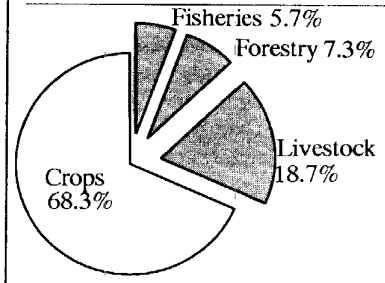
There are some limited regional disparities in the share of resources devoted to a particular commodity area (table 4). While such disparities are inevitable given regional variations in the pattern of production, it has been argued that less research is devoted to fisheries and forestry than their reported economic importance warrants. In fact the data, as shown in table 4, do not generally support this proposition. Research into forestry attracts more resources than its congruent share in agricultural output in all regions. In Asia & Pacific and West Asia & North Africa, this is also true of fisheries.

Nevertheless, the actual facilities for research into forestry and fisheries are limited, primarily because NARSs in less-developed countries are generally small. The majority (73%) of them employ fewer than 200 researchers in total, while only small percentages of these are engaged in research into fisheries or forestry.

Factor Shares

A major challenge for managers of research systems is to make the most effective use of available re-

Table 3: *Commodity Orientation of Agricultural Research in Less-Developed Countries, 1981-85 Average*



Research orientation	Expenditures	Researchers[a]
	(millions 1980 dollars)	*(full-time equivalents)*
Crops	2,480	53,100
Livestock	679	14,500
Forestry	266	5,700
Fisheries	205	4,400
Total	3,630	77,700

Note: The data on commodity shares for 83 countries were applied to the corresponding expenditure and researcher totals for 130 countries in order to derive these estimates.

sources. The best mix of spending on capital equipment, personnel, and operating costs will depend to a large degree on the relative availability and cost of research inputs, their quality, and the type of research being conducted. Since the most effective combination will differ between regions and change within a system over time, it is unrealistic to propose standards for determining the "optimal" mix of inputs in research. The data presented in this section should be regarded as indicative figures based on a sample of countries, not as economic optima to necessarily be targeted.

The available data suggest that in 1981-85 NARSs in less-developed countries on average devoted 19% of annual expenditures to investment in physical capital, compared with 8% in the US.

The higher share of spending on capital equipment by NARSs in less-developed countries supports the conclusion, also evidenced by their rapid growth, that at least until the mid-1980s, most were in an phase of expansion. During this phase, not only must capital stock be replaced each year but new capital stock must be purchased. The pattern of expenditures in the US, on the other hand, reflects that of a mature system, most of whose capital spending entails replacement of existing equipment. The emphasis in the US system has, moreover, been consistently towards greater investment in human capital rather than physical capital in recent years. Today the system performs with around 14 cents of physical capital for each dollar of human capital, compared with about 27 cents 50 years ago.

The contemporary pattern of expenditure in less-developed countries equals that of US experiment stations in their early years at the turn of this century, when the share of capital in total expenditures rose steadily to peak at 29% in 1912, before steadily falling. Physical capital (i.e., land, buildings, equipment, etc.) has claimed the same share of overall spending (about 8%) in US research stations for the past three decades.

A second factor in the higher share of capital costs in less-developed country NARSs is that capital items are often relatively more expensive in less-developed countries and they often lack adequate repair and maintenance facilities, leading to an early write-off of equipment. Factor substitution, where less expensive inputs are substituted for more expensive inputs, may counterbalance this effect somewhat but is not likely to outweigh it.

Table 4: *Regional Congruence between AgGDP and Agricultural Research Personnel, 1981-85 Average*

Region	Crops & Livestock		Forestry		Fisheries	
	AgGDP	Research	AgGDP	Research	AgGDP	Research
	%	%	%	%	%	%
Sub-Saharan Africa (22)[a]	88.6	87.3	4.7	7.3	6.6	5.4
Asia & Pacific, excl. China (10)	89.7	81.1	5.2	9.4	5.0	9.6
Latin America & Caribbean (20)	94.2	92.8	2.9	5.4	2.8	1.8
West Asia & North Africa (7)	95.9	91.6	2.4	5.7	1.7	2.7
Less-Developed Countries (59)	90.7	87.0	4.6	7.3	4.6	5.7

Note: Data may not add up exactly because of rounding.

[a] Bracketed figures represent number of countries included in the regional samples on which the AgGDP breakdown is based. The research personnel breakdown is based on regional samples that include a somewhat larger number of countries.

A Brief History of Public Agricultural Research

On-farm experimentation, tinkering, and learning by doing have been salient characteristics of farming since the dawn of agriculture. But the institutional innovation of the publicly supported agricultural research station is of a more recent origin, dating only from the second half of the 19th century. Starting in Germany, extensive systems of agricultural research stations were built up rapidly throughout Europe, North America, and also Japan during the latter part of the century. This laid the foundation for many of the contemporary agricultural research systems in these parts of the world.

In many less-developed areas the history of agricultural research was shaped to a large extent by each region's colonial history. Africa, the Caribbean, and substantial parts of Asia owe the origins of their public agricultural systems to former colonial powers.

In sub-Saharan Africa, Britain and to a lesser extent France, Germany, Belgium, and Portugal established agricultural research stations in their areas of influence, starting from the end of the 19th century. Although the expansion was somewhat erratic throughout the first half of the 20th century, extensive networks of agricultural research stations were in place by 1960 — when most African countries achieved independence. In the case of the British colonies, all agricultural research facilities were handed over to the new governments at the time of independence, and financial contributions by Britain as well as the provision of British researchers were reduced rapidly. France, however, retained the administration of agricultural research in its former colonies for a lengthy period after independence and still supports them through extensive bilateral agreements.

The institutional development of research in Asia followed a pattern similar to that of sub-Saharan Africa, with Britain establishing research systems in India and other British colonies, the Netherlands in Indonesia, and France in Indochina. As in sub-Saharan Africa, the research focused on export crops and was commodity-specific. After independence many Asian research systems underwent major reorganization and restructuring and have evolved into relatively large, complex systems. Striking an appropriate balance between decentralization and centralized coordination has been a continuing issue in policy and institutional design.

China's agricultural research system is the world's largest and most complex. China resisted colonial domination and did not inherit a research structure like most other countries in the region. The nation's first research station was established in 1902, but in the following 50 years only a few more were established. A research-system perspective emerged only after 1949. Subsequent development has been gradual and disrupted by periodic changes in political direction. However, since 1979 there has been a consistent effort to develop a coherent research system. Research at the national level is conducted by a large number of ministries, linked with research at the provincial and local levels through a wide range of collaborative programs.

Institutionalized agricultural research in Latin America was not broadly initiated until the 1930s. This was partly because colonial rule in the region ended before colonially sponsored agricultural research started elsewhere. It was also because the region had relatively abundant land and labor and did not face as much pressure to develop productivity-enhancing technologies as did other parts of the world. Ineffective governments that failed to supply adequate public services, including research, were also a factor. Most Caribbean island states adopted research systems from former colonial powers. Exceptions were Cuba, Haiti, and the Dominican Republic, which had achieved independence before public agricultural research was institutionalized and where the pattern of development more closely followed that of Latin America.

Research stations in North Africa date back to the late 19th century and were in most instances established by France and Great Britain. West Asian countries were protectorates rather than colonies. This, plus the region's limited agricultural production potential, meant that agricultural research stations were established here later than elsewhere and in most countries only date from after World War II.

Whereas salaries and operating costs in agricultural research expenditures represent service flows, capital expenditures represent additions to a stock. Thus, the high share of capital in annual spending may also exaggerate the actual share of capital in the services used to perform research. Capital equipment can last for many years, and a measure of service flow, rather than of expenditure, would probably reduce the share of capital actually used by a research system in any given year, particularly if such a system expands rapidly.

The recurrent costs of NARSs can be divided between salaries and operating costs. In less-developed countries, salaries tend to be lower and operating costs higher than in more-developed countries. In 1981-85 a sample of 43 less-developed countries on average spent 30% of recurrent expenditures on operating costs, compared with 25% in the US.

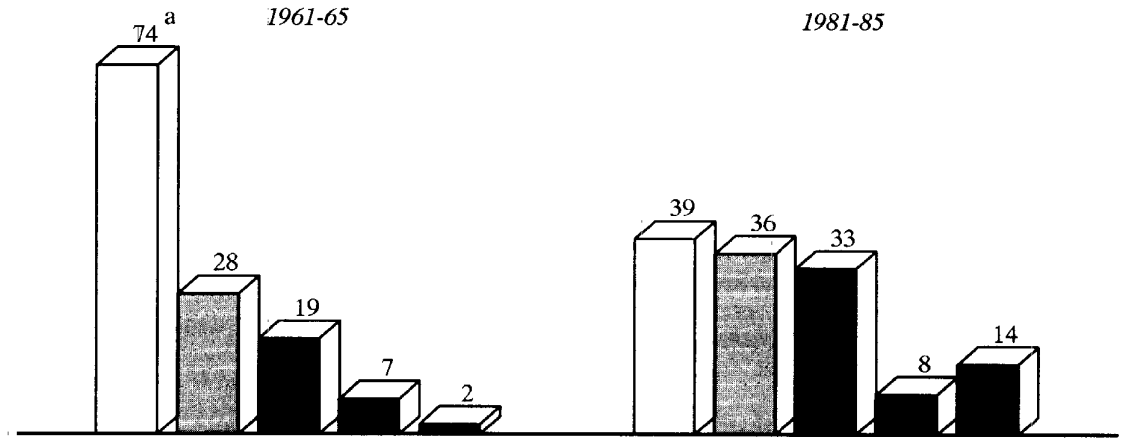
In 1981-85 NARSs in less-developed countries spent an average of $59,200 in constant 1980 dollars per researcher, compared with $99,100 per researcher in the US. The contemporary level of spending per researcher in less-developed countries again appears to mirror the situation in the early years of the US experiment stations. In fact, in the US total spending per researcher fell steadily in the early years as the recruitment of researchers outpaced rises in research expenditures. In the first 30 years, real operating expenditures per researcher fell to roughly a third of original levels and did not recover until the 1970s — some 60 years later!

One of the major difficulties in making plausible international comparisons of factor shares is that cross-country differences in price levels, which are not consistent across different expenditure items, act to confound the comparisons. Thus, if spending on operating costs and salaries is adjusted to take account of price differences between countries, research in less-developed countries is seen to be more labor-intensive relative to the US. Looked at this

way, the share of operating costs in recurrent expenditures in 1981-85 fell to an average of 15% in less-developed countries compared with the 30% noted earlier.

After adjusting for cross-country price differentials, operating expenditures per researcher are much smaller in less-developed regions than in the US. Agricultural researchers in sub-Saharan Africa, Asia & Pacific, Latin America & Caribbean, and West Asia & North Africa work with only 50%, 43%, 74%, and 22%, respectively, of the operating resources provided to a US researcher. However, the salary component of recurrent expenditures (including the salaries of both scientific and support staff) in the less-developed regions is much closer to the US level. And in sub-Saharan Africa it is even higher. This may be accounted for by the relatively high number of expatriates still working in African NARSs and the fact that the employment policies of many governments in less-developed countries result in NARSs employing large numbers of support staff.

Figure 3: *Distribution of less-developed country NARSs by size*



Legend: ☐ <25 researchers; ▒ 25-99 researchers; ■ 100-399 researchers; ■ 400-999 researchers; ■ >1000 researchers.

[a] Number of less-developed country NARSs

Size, Scope, and Spillovers

Since 1961-65, the average size of NARSs has more than doubled, from around 400 to 880 researchers, as has average expenditure per system. In less-developed countries the average size of NARSs has increased from 150 to 600 full-time equivalent researchers. Nevertheless, 95 of the 130 NARSs in less-developed countries still employ fewer than 200 researchers, while 39 systems employ fewer than 25 researchers. Only 14 employ more than 1000, illustrating that the growth and development of NARSs in the last two decades has diverged significantly (figure 3).

When analyzing the cost structures and effectiveness of a NARS, one needs to consider both the overall size and diversity of its operations and the agricultural system it serves.

The evidence on whether or not research operations are subject to economies of size is limited and far from definitive. In the case of a NARS, considerations of economies of size are confounded by the fact that these systems generate a wide diversity of products and services that vary in their commodity, technology, and agroecological specificity. For example, some activities relate to improving crops or developing new breeds of plants suitable for specific agroecological zones within a country. Alternatively, research can be devoted to developing improved crop and soil management practices that will allow farmers across a range of agroecological zones to increase yields or improve pest and disease control.

Even in the absence of scale economies with regard to any particular line of research (e.g., a particular commodity research program), a system may well be able to generate economies of scope through a judicious choice in its portfolio of research activities. Such scope economies arise when a system can undertake a whole range of research endeavors more cheaply than if these endeavors were undertaken by separate research entities. These economies can be achieved, for example, by sharing staff, equipment, information, or know-how between different lines of research.

An important implication of this is that when a system can create sufficiently strong economies of scope, these can in turn lead to economies of scale across the whole range of its activities, even if such economies of scale do not arise for some individual research programs.

Of course there can also arise diseconomies of scope, particularly among small systems that spread their limited resources across disparate research areas. Thus, small NARSs will be unable to conduct research in all areas that may warrant attention in the agricultural systems they serve. They will have to make choices between areas of study, and this in turn

requires some specialization and flexibility in response to opportunities as circumstances change.

The efficiency of a research system can also be increased by adapting research conducted elsewhere to local circumstances. The ability to capture research spillovers is particularly important for small NARSs without the capacity to conduct much basic research themselves. The best source of spillover would seem to be neighboring countries with similar agricultural systems and agroecological features. This strategy would require a policy of hiring staff for their ability to adapt research to local situations rather than to carry out original research. It also requires flexibility in the research system to identify and act upon opportunities arising from developments elsewhere.

There is some disturbing evidence that many smaller NARSs are unable to take up information quickly enough and that the knowledge they work with is increasingly out of date. In a world of growing international interconnectedness, harnessing spillover from other research systems is most effective if it can be adapted to local circumstances in a timely manner. Using out-of-date information only undermines a country's relative technological capacity and therefore its competitiveness.

Research and Productivity

There is a temptation to measure the success of agricultural research in terms of total agricultural output per unit of research expenditure in a way similar to the earlier productivity measures for land and labor.

But research can probably best be seen as an investment activity. The research process itself takes time, and a further period elapses before the results of research are taken up. Recent evidence suggests, furthermore, that agricultural research can still have an effect in increasing output for as long as 30 years after the research was initiated. So to consider gains in AgGDP as a measure of the impact of contemporaneous research expenditure could be misleading.

As mentioned earlier, differences in the quality of land and labor, and the relative use of other inputs such as fertilizers and machinery, will influence output and thus distort international comparisons of productivity that are measured only in terms of research.

Bearing these cautions in mind, one can see that

Private Research

Any formulation of future public-sector research policy must take into account the level of activity and changing role of the private sector in agricultural research. The private sector's increasing participation in and funding of research will (re-)shape research priorities and the most effective deployment of public-sector research resources.

In the more-developed countries, the private sector plays a significant role in agricultural research. Recent figures indicate that in the US and Britain, for example, privately sponsored and executed research accounts for about 60% of total (including postharvest) agricultural research expenditures.

Although a paucity of data makes comparisons difficult, for less-developed countries a current best estimate would be unlikely to exceed 10%. Much of this research is located in Latin America and Asia and is concentrated in a few large countries such as Brazil, Mexico, Argentina, and India. The bulk of this research is performed by those local and multinational companies engaged in the farm-input supply industries (e.g., seeds, fertilizers and other chemicals, and machinery) with some limited research occurring in the food-processing sector. But, as the level of purchased inputs in production agriculture increases and the value-added in agriculture increasingly moves off-farm to the marketing and processing sectors, it is likely that the incentives for private-sector investment in research in less-developed countries will grow.

Three groups of factors influence the nature and level of private agricultural R&D investments: (a) market factors, such as the expected growth in demand for agricultural products, derived demand for modern agricultural inputs, and factor prices facing farmers and agribusiness, (b) the ability of firms to appropriate benefits from new technology, and (c) the technological opportunities for producing profitable products.

Governments have a number of policy instruments with which to influence private R&D. Public-sector research can foster private-sector research by providing (or selling) research results and by training the personnel needed by private companies to conduct research. Patents and plant variety protection laws, if they are well designed and enforced, can create the necessary incentives for private companies to invest in R&D. Technology imports can stimulate local R&D, so more liberalized technological trade could also increase local private-sector R&D activities.

Innovative institutional arrangements can also help foster those complementarities that exist when the generally more upstream or "pretechnology" types of research best suited to the public domain are married with the more applied, technology-generating types of research best suited to the private domain. For instance, joint-venture research endeavors, where both public and private agencies jointly undertake and/or cofinance a program of research are becoming more frequent. Fee-for-service or contract research is also increasingly being used to privatize the financing of research being performed by public-sector research institutions.

Private, for-profit research should not be seen as something intrinsically detrimental to the public good, but neither is it likely that an unfettered private sector has the incentive to invest sufficiently in researching those problems that will optimize social welfare. Public-policy formulators will need to become increasingly sensitive to a rapidly changing technological and institutional environment in order to take advantage of the opportunities that exist to mobilize both private and public research resources in a socially desirable manner.

HUMAN CAPITAL IN RESEARCH

One of the fundamental strengths (or, too often, weaknesses) of NARSs, and a major factor in determining the success of agricultural research, lies in the quality, composition, and deployment of their research staff.

Developing meaningful measures of this human capital component is challenging both conceptually and practically. Indicators such as university qualifications and years of research experience may explain much of the difference in quality between research systems, but they are not the only factors. The composition of the research staff will depend, among other things, on the NARS's size and the type of research it is conducting. These influences vary greatly between regions and will change within a system over time. For instance, a smaller NARS whose activities are focused more on capturing research spillovers and adapting them to local circumstances is unlikely to need a cadre of researchers similar to that required by a large NARS that is likely to confront an altogether different scale and set of research problems. Similarly, while a system dominated by researchers holding PhDs and 20 years of experience may be considered highly qualified, it is not necessarily the most appropriate labor force to confront the applied and site-specific problems that face many national research systems today.

Data for the period 1981-85 indicate that roughly one-half of agricultural researchers, including expatriates, in less-developed countries held a postgraduate degree, either an MSc or PhD. If expatriate researchers are excluded from the calculation, no less-developed region has a share of researchers with a postgraduate qualification greater than 60%, and in a significant number it is lower than 40%. Among more-developed countries, this proportion appears to be between 70% and 90%. Somewhat surprisingly, poorer less-developed regions have a relatively high proportion of qualified staff, although that is much lower if expatriate researchers are excluded from the calculation.

Expatriate Researchers

In many less-developed countries the early agricultural research institutes were established by European colonial powers and during the first half of this century these institutes were staffed with expatriate researchers. On independence, most former colonies moved to replace expatriates with national researchers. In some countries this change took place gradually but in others it was more abrupt and caused major disruptions in agricultural research programs. At present, only the smaller countries of sub-Saharan Africa, the Caribbean, the Pacific, and the oil-rich countries of West Asia have relatively large proportions of expatriates on their research staffs. The share of expatriates is declining rapidly however. In sub-Saharan Africa, for example, the share of expatriates in NARSs was about 90% in 1960 but had declined to some 30% by the early 1980s.

Making the plausible assumption that the number of expatriate researchers working within the Chinese and Indian systems are negligible, the percentage of expatriate researchers working throughout the less-developed world in 1981-85 is estimated to be around 3%.

Optimum Composition of Staff

Although economic development can be expected to increase the supply of university graduates, research systems in some of the wealthier less-developed countries appear to have difficulty recruiting or retaining qualified staff. In part, this is because salaries in public agricultural research institutes are not competitive with other job opportunities. In a number of countries, for example, universities employ large numbers of PhDs in the agricultural sciences, while the national public agricultural research institutes employ few or none.

On the other hand, as argued earlier, a large proportion of PhDs on the research staff does not necessarily indicate a successful research program. The contemporary systems of Australia and New Zealand, for instance, have apparently achieved significant successes with a high proportion of staff trained to the BSc or MSc level, as did the US system in earlier years. While not discounting the value of training researchers to the PhD level, these observations would suggest that greater attention should be given to the research orientation and training within BSc and especially MSc programs at local universities rather than simply seeking a high proportion of PhDs through training abroad, particularly when such training is of questionable relevance.

Status of Agricultural Researchers, 1981-85 Average

	Expatriates	Share of Postgraduates[a]
	%	%
Sub-Saharan Africa[a]	29	45
Asia & Pacific[b]	11	53
Latin America & Caribbean	2	51
West Asia & North Africa	18	27
Less-Developed Countries[b]	12	48
Australia	na	57
New Zealand	na	78
United States	na	93

[a] Measures the proportion of national researchers holding a PhD or MSc degree or equivalent. Figures for Australia and New Zealand are for 1981 and for the United States are 1980 only.
[b] Does not include China and India, the two major NARSs in the region.

output per dollar spent on research fell by roughly one-half between the early 1960s and 1980s in both more- and less-developed countries (table 5). If diminishing returns apply to research, so that the incremental productivity gains to be had from it occur at a diminishing rate, this result could be expected if investment in research on specific production systems steadily increased, as indeed occurred.

In fact, all the more- and less-developed regions continued to increase their research intensities during that period (table 6). In 1981-85 less-developed countries spent an average of nearly $4 per agricultural worker on research, 2.5 times the amount spent two decades before. In more-developed countries, spending on research increased 4.4 times over the same period, to $214 for every agricultural worker.

There are a number of extra factors that affect the impact of research in a particular region. Research tends to be more effective in countries with a benign climate and a small range of commodities. Similarly, countries with a wide diversity of production systems, ranging, for example, from subsistence farming to commercial plantations, are likely to reap less benefit per research dollar than a country where all production and marketing take place under similar circumstances.

A final factor urging caution in assessing the benefits of research in terms of increasing AgGDP is that a large share of agricultural research may be directed towards maintaining gains from earlier research rather than enhancing output levels per se. Recent estimates suggest that in the US around one-third of research expenditures are spent on maintenance, and it is probable that many less-developed countries devote at least as much.

Table 6: *Agricultural Research Factor-Intensity Ratios*

Region	Agricultural research expenditures					
	1961-65	1971-75	1981-85	1916-65	1971-75	1981-85
	Per economically active person in agriculture			*Per hectare of agricultural land*		
Sub-Saharan Africa (37)[a]	1.7	2.7	3.1	0.2	0.4	0.6
China	0.9	1.4	2.2	0.6	1.2	2.2
Asia & Pacific, excl. China (15)	1.2	2.2	3.4	1.0	2.1	3.6
Latin America & Caribbean (26)	6.5	12.8	17.7	0.4	0.7	1.0
West Asia & North Africa (13)	4.5	10.5	14.3	0.4	1.0	1.4
Less-Developed Countries (92)	1.5	2.7	3.8	0.5	0.9	1.7
More-Developed Countries (18)	48.6	119.1	213.5	1.8	3.1	4.0
Total (110)	4.4	7.0	8.7	0.9	1.6	2.3

Note: All expenditure figures are in constant 1980 dollars.

Table 5: *Agricultural Research "Partial-Productivity" Ratios*

Region	1961-65	1971-75	1981-85
	AgGDP per dollar of research expenditures		
Sub-Saharan Africa (37)[a]	390	238	202
China	243	254	254
Asia & Pacific, excl. China (15)	701	452	314
Latin America & Caribbean (26)	328	215	173
West Asia & North Africa (13)	351	199	192
Less-Developed Countries (92)	422	293	244
More-Developed Countries (18)	104	71	49
Total (110)	205	144	117

Note: All expenditure figures are in constant 1980 dollars.

INTERNATIONAL AGRICULTURAL RESEARCH

Contrary to the situation in many areas of scientific research, there has always been an important element of international cooperation in agricultural research. Much of this is due to the legacy of the colonial relationships that existed at the time institutionalized agricultural research was developing.

One of the leading international organizations in the field is the Consultative Group on International Agricultural Research (CGIAR), an umbrella body of around 40 donor countries and international agencies that foster the activities of 13 supranational research centers. (Recently this number was enlarged but our discussion here refers to the original 13.) Ten of these centers have their headquarters in less-developed countries. The majority are engaged in research into either food commodities or agricultural production problems in a particular tropical region, and three undertake worldwide research into specific commodities.

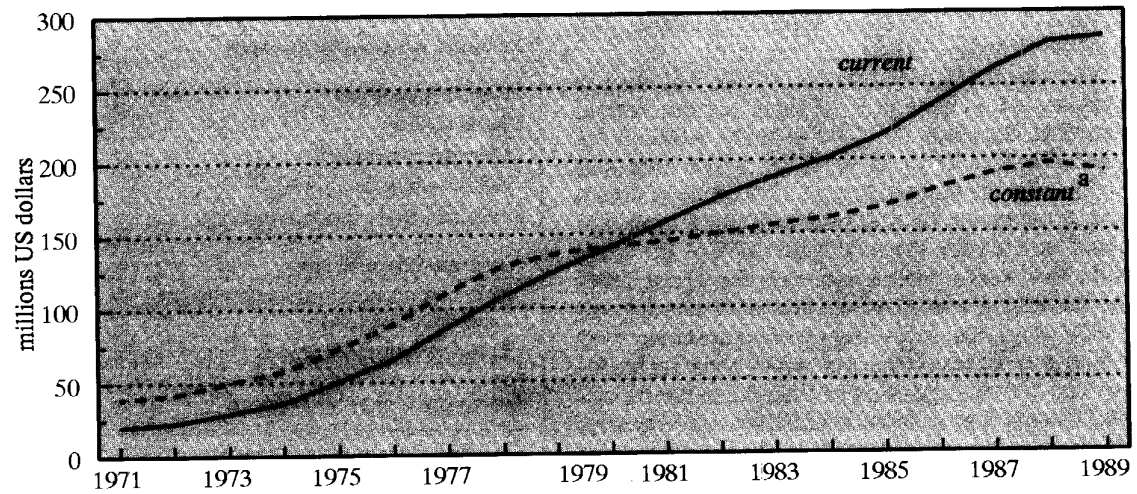
Established in 1971, the stated objective of the CGIAR (CG for short), was to assist efforts to increase food production in the less-developed world. In 1990 the goals were extended, in recognition of agriculture's broader role in economic development, to helping less-developed countries achieve self-reliance in food. Self-reliance is taken to mean the capacity of a country to provide sufficient food for its population, either directly through local food production or indirectly by generating agricultural exports that will allow food to be imported.

The activities of the CG can today be broadly defined as seeking to enhance sustainable agricultural production through resource conservation and management, to increase the productivity of commodity production systems, to improve the policy environment, and to strengthen national research systems. When establishing research priorities, the centers within the CG increasingly stress the spillover potential of their research results across regions or agroecological zones.

The CG is assisted in its work by a Technical Advisory Committee (TAC), which now has 18 members and a chairperson and meets three times a year. TAC proposes priorities and strategies for the group, reviews the quality and relevance of center programs, and makes recommendations on resource allocations among centers. It is supported by a secretariat located at FAO headquarters in Rome. The CG also has a secretariat that deals primarily with donor relations, financial matters, and management issues, based at the World Bank in Washington, DC.

In 1981-85, the CG accounted for only 1.8% of global public-sector spending on agricultural research, 4.3% if related to spending by and for less-developed countries. Its budget rose, in nominal terms, from $20 million contributed by 20 donors in 1971, to $280 million from 40 donors in 1990. If corrected for inflation, the CG expenditures clearly show different phases of growth (see figure 4). Rapid expansion during the 1970s was followed by slower

Figure 4: *CGIAR expenditures, 1971-1990*



[a] Base year = 1980.

growth during the 1980s and apparent stagnation or even decline in the last few years.

The US remains the largest single donor to the CG, although both Europe and Japan increased their share of contributions during the 1980s. The World Bank acts as a balancing "donor of last resort," allocating its funds after other donor intentions are known. It usually contributes around 15% of the system's total budget each year.

During the 1980s, although the CG was established partly in response to the high levels of poverty and hunger in Asia, the emphasis in the allocation of funds has shifted to sub-Saharan Africa. Between 1986-88, sub-Saharan Africa accounted for 39% of the CG's core expenditures, compared with 26% to Asia, 21% to Latin America & Caribbean, and 14% to West Asia & North Africa.

The "appropriate" regional allocation of funds is just one of the policy issues facing the CG. Although much of the increase in funding directed to sub-Saharan Africa has been for special projects, it is arguable that the concentration of resources has swung too much towards that region at the ultimate expense of Asia, which has several-fold more poor than sub-Saharan Africa.

The commodity orientation of the system has been subject to change over time. As the system expanded, the share allocated to cereal research declined steadily to about 40%, of which rice still accounts for the largest share at 17% of the system's total. Food crops, such as potatoes, other roots and tubers, and legumes, account for 24% of the total, while livestock research accounts for about 20%. The remaining resources are allocated to noncommodity programs, including farming systems, food policy, genetic resources, and NARS capacity building. The current expansion of the system has broadened its coverage to include fisheries, agroforestry, and bananas and plantains. It will also eventually include forestry and horticultural commodities.

There are considerable differences among regions in the commodity or activity orientation of the CG's endeavors (see table 7). Research on cereals is focused on Asia, while research on food legumes appears to be relatively equally balanced between

Table 7: *CGIAR Core Operating Expenditures by Category, Apportioned by Geographic Region, 1986-88 Average*

	Sub-Saharan Africa	Asia & Pacific[a]	Latin America & Caribbean	West Asia & North Africa
	%	%	%	%
Research activities				
Rice	28	63	8	0
Wheat, barley, triticale	21	14	20	44
Maize	43	18	34	6
Sorghum, millet	53	42	5	0
Subtotal, cereals research	33	*40*	*16*	*11*
Potatoes	30	15	45	10
Other roots & tubers	45	0	55	0
Legumes	18	30	27	25
Subtotal, crop research	30	*33*	*24*	*13*
Livestock	68	0	21	11
Subtotal, commodity research	39	*25*	*23*	*13*
Farming systems	43	28	0	29
Food policy	42	55	2	1
Genetic resources[b]	25	25	25	25
NARS capacity building[b]	25	25	25	25
Subtotal, other research/activity	38	*33*	*8*	*22*
Nonresearch activities				
Information, communication, library, and documentation	47	22	18	13
Training and conferences	40	30	21	9
Total operating expenditure	39	**26**	**21**	**14**

Note: Totals may not add up because of rounding.
[a] Includes China.
[b] In the absence of regional details concerning these expenditure categories, CGIAR data indicate an equal distribution across regions.

the four major less-developed regions. CG-sponsored activities on roots and tubers are predominantly focused on sub-Saharan Africa and Latin America, while almost 70% of its investment in livestock research is concentrated in sub-Saharan Africa. Research on genetic resources is equally divided between the four regions. Research on farming systems is largely concentrated in sub-Saharan Africa and West Asia & North Africa and is now receiving little attention in Latin America. Most of the food policy research is concerned with Asia and sub-Saharan Africa. Training efforts mirror the overall allocation of operating expenditures.

The 1990 reorientation of the CG's objectives to emphasize self-reliance instead of self-sufficiency in food was a recognition of the fact that increasing food production is not in itself a solution to the hunger problem. Future policies must reflect the role of agricultural growth as a means of generating additional on-farm and off-farm income and employment and the need to sustain the natural resource base on which continued gains in agricultural productivity depend.

The CG's initial efforts were largely targeted toward more favorable production environments. Technology packages were developed that involved higher rates of fertilizer applications and improved water management and cultural practices, along with new crop varieties that were particularly responsive to more intensified production regimes. While the dramatic contribution of these technology packages to increasing global food supplies is unquestioned, by the mid-1970s the CG had also begun to address production constraints in the more marginal environments of the semi-arid and (sub-) humid tropics.

At present about 30% of CG funding is targeted towards technology for marginal lands, which is roughly equal to the percentage of the poor population in less-developed countries that live in these areas. The issue of the relative merits of developing favorable versus marginal lands will continue to be an important one for the CG, particularly with respect to the potential opportunity costs (in terms of productivity gains foregone) of diverting scarce research resources away from potentially more responsive areas towards the more marginal ones.

It is likely that as national research systems continue to grow and develop, they will be able to undertake an increasing share of the adaptive and applied research presently conducted by CG centers. The CG has already begun to encourage the centers to engage in more pretechnology and strategic research with greater spillover potential.

Research on resource management will become more important as the need for continued increases in food production place an ever greater strain on the world's natural resources. The CG has taken steps in this direction. Strategies on how best to include agroforestry and to pay greater attention to resource management concerns in the system's research program are currently being implemented. This is being done by expanding the system and redesigning its approach in order to incorporate institutional entities that specifically address research concerns within an agroecological perspective. Aware of the fact that socioeconomic—not just natural—conditions constrain the effectiveness and spillover potential of the system's research, this agroecological aspect is being overlaid on a geopolitical or regional dimension to generate a so-called "ecoregional" perspective.

In addition to the 13 CGIAR centers discussed here and nine kindred centers (some of which are now members of the CG system), about 52 other multilateral agricultural research and research-complementing institutions based in less-developed countries were identified in 1985. Of these 52, only 17 were directly involved in conducting agricultural research. The remaining 35 filled a research-support role by providing training, coordination, information, and extension services in addition to financial and professional support for agricultural research agencies. Financial institutions such as the World Bank and the regional development banks are excluded from this tally even though they have also supplied some support other than directly through their lending programs.

Table 8 indicates that only two of these institutions work in more than one region. Of note is the high concentration of multilateral agricultural research and research-complementing institutions in sub-Saharan Africa. The majority of these have a

Table 8: *Other Multilateral Agricultural Research and Research-Supporting Institutes Based in Less-Developed Countries, 1985*

Mandated region	Total number	Executing research	Funding sources		
			Local	International	Mixed
Global	2	1	0	0	2
Sub-Saharan Africa	21	3	5	6	10
Asia & Pacific	12	3	2	2	8
Latin America & Caribbean	14	9	3	0	11
West Asia & North Africa	3	1	3	0	0
Total	52	17	13	8	31

research-support function, with only three of the 21 in the region conducting any agricultural research. The region with the largest number of multilateral institutions actually conducting agricultural research is Latin America & Caribbean, including some subregional agencies such as CARDI in the Caribbean and CATIE in Central America. Only three multilateral institutions are reported for the West Asia & North Africa region.

An institution can be defined as being internationally funded if most of its funds are provided by donors outside the region, mixed if both local governments as well as donors from outside the region provide funding, and local if most of the funds are provided by local governments. Only one-quarter of the multilateral institutions identified in table 8 are funded solely by their client governments. In most cases, the existence of the multilateral institutions in less-developed countries is heavily dependent on funding from outside the region in which they are operating. In many instances, Western donors have been the driving force behind the creation of these institutions, and their existence in practice often has little to do with regional cooperation. Such cooperation is often impeded by political instability, strong nationalistic tendencies, and a prevalence of national institutions that are too weak to effectively participate. The future of regional approaches to agricultural research, particularly in sub-Saharan Africa and Latin America & Caribbean, is presently under active policy review.

Another layer of agricultural research activities that transcend national boundaries is bilateral tropical agricultural research. Most European colonial powers had built up considerable colonial agricultural research systems by the time their colonies achieved political independence. In the post-colonial era, there has been a strong shift from institutionalized program support to project-oriented donor activities in agricultural research. This has involved a changing cast of actors, with the expertise once found primarily in colonial services now residing variously in universities, specialized research organizations, and increasingly, in private consulting firms that manage competitively won projects.

Political and Financial Support for Agricultural Research

A fundamental task facing NARSs is to win public support for research and translate it into financial support. This must be done in the context of a public sector subject to competing claims on its scarce resources from various interest groups in society, be they producers, consumers, or taxpayers.

From this perspective, governments give differential preference to various programs both within and between sectors of the economy in response to such pressures. Thus, agricultural expenditures are committed to such programs as rural infrastructure, education, and credit as well as to the generation and dissemination of new agricultural technologies. In addition, many poor countries implement distortionary pricing and marketing policies in the (short-run) pursuit of cheap food policies and the like, which ultimately tax agriculture and accelerate the transfer of resources from the sector. These same policies, in part by undervaluing sector-specific assets in agriculture (e.g., land and irrigation facilities), can also lead to underinvestment in agricultural research and to a low level of effort invested by farmers in searching for, evaluating, and adapting new agricultural technologies and practices.

To gain a full understanding of the observed disparities in the nature and level of support for agricultural research (and the ultimate productivity effects that flow therefrom) would require detailed consideration of these "political economy" forces — an exercise that would take us well beyond our brief. Rather, the aim here is to present comparative evidence on the level of support for public agricultural research and to place publicly funded research in the context of the overall level of support for agriculture.

A traditional measure of the level of support for agricultural research is the agricultural research-intensity ratio that expresses levels of research spending as a percentage of AgGDP. In figure 5 we have plotted this ratio for the period 1981-85 for as many countries as possible.

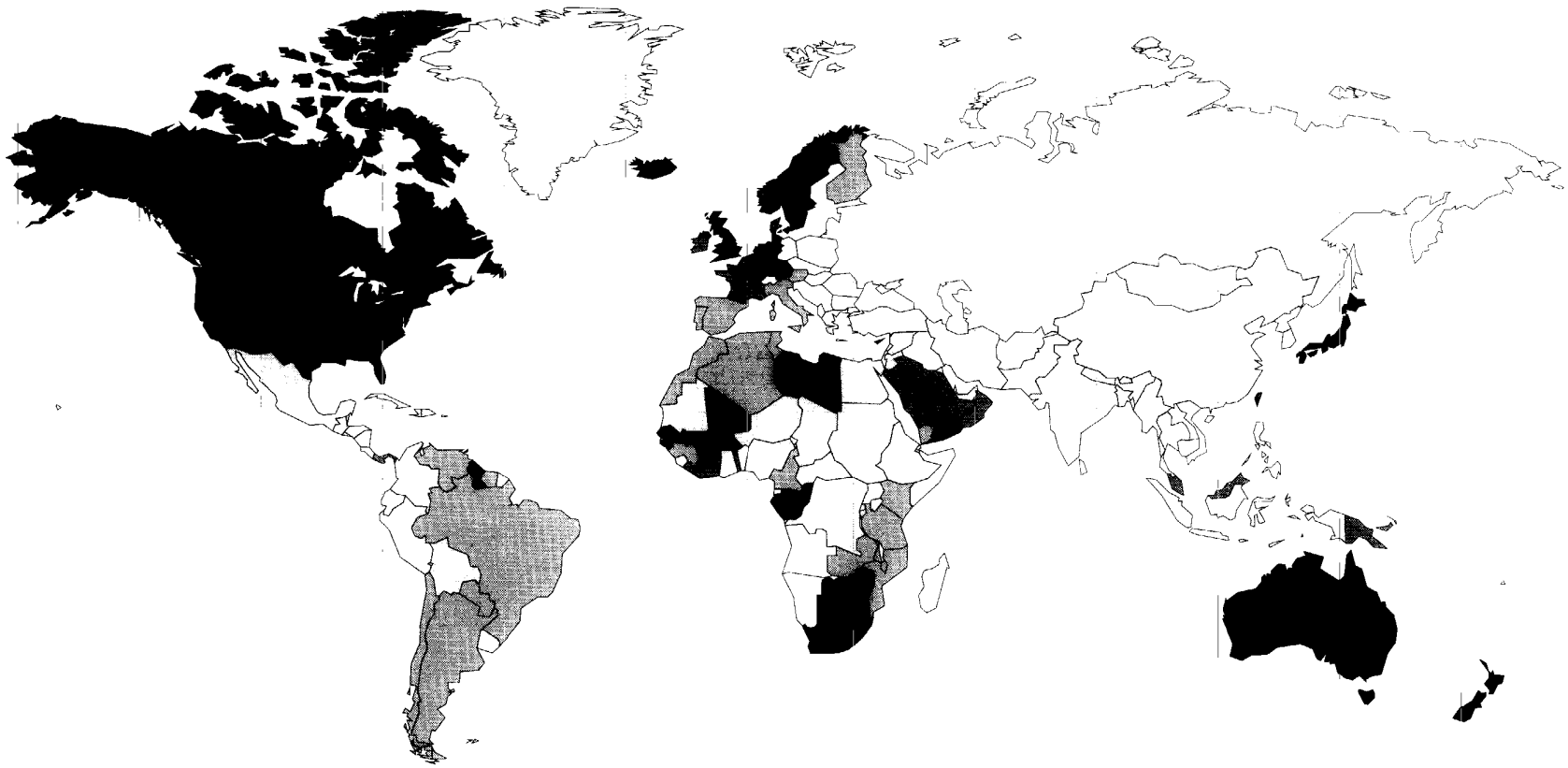
Although the majority of the less-developed countries spent well above 0.5% of AgGDP on agricultural research in 1981-85, the weighted average was only 0.4% (table 9). This apparent difference

Table 9: *Agricultural Research-Intensity Ratios by Region and Income Group, Weighted Averages*

Region[a]	1961-65	1971-75	1981-85	Income group[a]	1961-65	1971-75	1981-85
	%	%	%		%	%	%
Sub-Saharan Africa (37)[b]	0.26	0.42	0.49	Low (30)	0.22	0.27	0.35
China (1)	0.41	0.39	0.39	Lower-middle (28)	0.24	0.35	0.40
Asia & Pacific (15)	0.14	0.22	0.32	Middle (18)	0.25	0.46	0.57
Latin America & Caribbean (26)	0.30	0.46	0.58	Upper-middle (18)	0.27	0.44	0.55
West Asia & North Africa (13)	0.28	0.50	0.52	High (16)	1.08	1.57	2.23
Less-Developed Countries (92)	0.24	0.34	0.41	Total Sample (110)	0.48	0.65	0.76
More-Developed Countries (18)	0.96	1.41	2.03				

[a] Countries assigned to income classes based on 1971-75 per capita GDP averages where low is <$600; lower-middle is $600 – $1499; middle is $1500 – $2999; upper-middle is $3000 – $5999; and high is ≥ $6000.
[b] Bracketed figures represent number of countries in each region or income class.

Figure 5: *Agricultural research-intensity ratios, 1981-85 average*



Legend: 0.5% <; 0.5 - 1.0%; 1 - 1.5%; 1.5 - 2%; > 2%; na

between simple and weighted average is caused by the fact that the smaller less-developed countries tend to have substantially higher agricultural research-intensity ratios than the large less-developed countries. The weighted average of the more-developed countries barely reached 2% in 1981-85. The Southern European countries lagged significantly behind the other more-developed countries. When calculated by income group, a (not so surprising) strong correlation appears between per capita income and the agricultural research-intensity ratio.

Although agricultural research-intensity ratios approximately doubled in both more- and less-developed countries between 1961-65 and 1981-85, they declined in the latter half of that period in 37% of the less-developed countries, half of which were in sub-Saharan Africa.

Research investment has traditionally produced high levels of return compared with investments in other areas, up to and exceeding 35% in some instances. This fact, and the gap in investment with more-developed countries, have led some authorities to conclude that many less-developed countries underinvest in agricultural research. It has also led to calls from the World Bank, for example, to set a research investment target of 2% of AgGDP.

Research-intensity ratios are useful to policymakers because they indicate the importance other countries attach to agricultural research. But they may be an unreliable indicator of the appropriateness of a nation's research investment because the efficacy of a country's research endeavor differs between regions and over time. It could therefore be more helpful, instead of setting arbitrary targets for research investment, to fix a desired rate of return from the investment made — to set targets that would push rates of return below 20%, for example.

The data presented in table 10 show that low-income countries spend a considerably greater share of overall public expenditures on agriculture and agricultural research than high-income countries, around 11% on agriculture and 0.7% on agricultural research, compared with 3% and 0.2%, respectively, in high-income countries. Moreover, the share of public expenditures on agriculture directed specifically to research remains surprisingly constant, at around 8% in 1981-85, for both poor and rich countries alike. This contrasts markedly with the data in table 9 that report agricultural research-intensity ratios for poor countries that are substantially lower than those for rich countries.

To understand why this is so would involve, at a minimum, a detailed consideration of the decision-making processes whereby public research investments, pricing policies, and the like are jointly determined. Particular attention would need to be given to the relative incidence of research benefits and costs (across producers, consumers, and taxpayers) in relation to alternative policy instruments — investing in rural public goods such as agricultural research versus taxes, subsidies, and production quotas. Nevertheless the macro-level data in table 11 are suggestive of the general nature of the political economy forces at work.

Table 10: *Agricultural and Agricultural Research Shares in Public-Sector Expenditures*

Income group[a]	1971-75	1976-80	1981-85
	Percentage of agricultural expenditures in total government expenditures		
Low (13)[b]	10.5	11.7	11.2
Lower-middle (18)	7.5	8.1	9.3
Middle (12)	6.5	5.7	5.2
Upper-middle (12)	6.7	4.7	4.3
High (15)	3.0	2.7	2.5
Total sample (70)	7.1	6.9	6.8
	Percentage of agricultural research expenditures in total government expenditures		
Low (13)	0.8	0.7	0.7
Lower-middle (18)	0.7	0.5	0.6
Middle (12)	0.5	0.4	0.4
Upper-middle (12)	0.2	0.2	0.2
High (15)	0.3	0.2	0.2
Total sample (70)	0.5	0.4	0.4

Note: All data represent simple averages across all countries in each income class.

[a] Countries assigned to income classes based on 1971-75 per capita GDP averages where low is < $600; lower-middle is $600 – $1499; middle is $1500 – $2999; upper-middle is $3000 – $5999; and high is ≥ $6000.

[b] Bracketed figures represent number of countries in each income class.

The table shows that in high-income countries, total annual government spending on agriculture per head of *agricultural* population was 86 times greater than in low-income countries for the 1981-85 period. However, this difference drops dramatically, to a factor of 8, if one compares government spending on agriculture per head of *total* population for the two groups of countries during the same period. Per capita spending on agricultural research follows a similar pattern. Thus, as one moves from low- to high-income countries, the level of per capita "benefits" or transfers accruing to rural-based coalitions may well increase at a disproportionately larger rate than the per capita incidence of "costs" associated with such programs. If this were the case, then the willingness of rural-based coalitions to lobby governments in support of agricultural research (and other forms of interventions that transfer resources to agriculture rather than the nonagricultural sector) may in turn be positively associated with per capita income.

Table 11: *Annual Public Spending on Agriculture and Agricultural Research (Constant 1980 Dollars)*

	Government expenditure on agriculture			Agricultural research expenditures		
Income group[a]	1971-75	1976-80	1981-85	1971-75	1976-80	1981-85
			Per head of agricultural population			
Low (13)[b]	14.0	18.9	21.1	0.9	1.1	1.3
Lower-middle (18)	44.0	69.5	102.1	3.7	4.0	5.3
Middle (12)	77.8	94.8	119.2	5.5	6.1	7.6
Upper-middle (12)	218.8	358.7	552.3	12.6	19.8	26.5
High (15)	1338.2	1423.1	1801.0	91.8	113.2	140.6
Total (70)	*362.4*	*404.1*	*531.2*	*23.9*	*29.9*	*37.6*
			Per head of total population			
Low (13)	10.0	13.4	14.1	0.7	0.8	0.9
Low-middle (18)	20.9	29.6	38.7	1.5	1.8	2.3
Middle (12)	31.6	35.3	38.1	2.4	2.3	2.6
Upper-middle (12)	66.0	62.1	73.0	2.2	2.5	2.7
High (15)	111.5	112.4	115.0	7.3	8.1	8.5
Total (70)	*47.9*	*50.9*	*56.3*	*2.9*	*3.2*	*3.5*

Note: All data represent simple averages across all countries in each income class and are expressed in constant 1980 dollars.

[a] Countries assigned to income classes based on 1971-75 per capita GDP averages where low is < $600; lower-middle is $600 – $1499; middle is $1500 – $2999; upper-middle is $3000 – $5999; and high is ≥ $6000.

[b] Bracketed figures represent number of countries in each income class.

Emerging Issues

The current world population of a little over 5 billion could double by the year 2030. This continued population growth, coupled with an increase in per capita income, particularly in the less-developed world, will place unprecedented pressure on the world's agricultural system to meet the increased demands for food and fibre.

There are two major areas of concern relating to agriculture's ability to meet these demands. The first is the fear that available natural resources, such as water and land, are deteriorating to the extent that the necessary growth in production cannot be achieved and maintained. The second is the contribution of intensive agriculture to environmental damage, particularly global warming.

The issues that will place the greatest demands on the agricultural research system can be classified under two broad headings: (a) technological and biological factors and (b) resource and environmental factors.

Technological and Biological Factors

Almost all the increases in farm output required to meet global needs well into the second decade of the next century must come from further intensification of production practices on existing agricultural lands. Conventional production practices and technologies are unlikely to be replaced by "new-generation" technologies in the short term. But productivity gains from conventional sources are likely to come in smaller increments than in the past, and to an increasing degree, these gains are likely to be crop-, animal-, and location-specific.

This suggests that a greater emphasis must be given to improving farm management skills in order to make more efficient use of fertilizers and other (purchased) inputs and to improve the control of agricultural pests and diseases, along with the management of the agricultural resource base (e.g., land and water). Productivity gains will come primarily from increased knowledge of specific land and crop systems. For the benefits to spread throughout the globe, more emphasis must be given to sharing and transferring information and management practices, not simply new technologies, between systems.

One approach is for both national and international agricultural research systems to increase the proportion of resources devoted to improving agronomic and livestock management practices relative to genetic improvement programs.

It is also the case that an increasing share of the new knowledge generated by research will reach producers in the form of proprietary products or services. This means that the incentives must exist to draw substantially more private-sector resources into agricultural research. This will enable public-sector research organizations to focus their research efforts on those more basic or pre-technology areas where the private sector has fewer incentives to invest. Rationalizing regulatory regimes will play a large role in determining the profitability of research investments as well as the international transfer of new agricultural technologies.

Resource and Environmental Factors

The second category of concerns includes issues of resource and environmental constraints as they relate to our ability to achieve sustained growth in agricultural production. On the one hand, intensive farming in the recent past has led to wide-scale pollution of ground and surface water supplies by fertilizers and pesticides, to soil erosion in many regions, and to the accelerated development of resistance by many pests to chemical control. This raises doubts about the ability of the natural resource base to sustain continuing growth.

The other aspect of the problem is the contribution of agriculture to global warming and acid rain, and the effects climatic change may have on future agricultural production. Global warming will almost certainly lead to some (currently unknown) rise in the earth's surface temperature over the next half century. The prime causes of global warming are emissions of so-called greenhouse gases, principally carbon dioxide, nitrous oxide, and methane.

Industry is the largest producer of carbon dioxide emissions, but agriculture is estimated to contribute around 25% of the gases that cause global warming. The extensive burning of tropical rain forests, much of it carried out to produce agricultural land, not only contributes heavily to the production of greenhouse gases but seriously reduces the planet's capacity to recycle carbon dioxide. Nearly 50% of nitrous oxide emissions come from soils, fertilizers, and forest clearance. Agriculture is also the source of most methane releases.

Without substantive institutional reforms at the national and international level, efforts to prevent changes in climate by curbing harmful emissions appear unlikely to succeed in the foreseeable future. Although there may be progress in reducing indus-

SUSTAINABILITY

Some General Principles

The concept of sustainability encompasses a wide variety of concerns regarding the potential for economic development to run into resource and environmental constraints, retarding future progress. To move beyond broad generalizations toward an operational definition of sustainability (that has implications for research policy) is problematic. Nevertheless, given the potential long-term importance of these concerns, the sustainability concept is likely to play a role in research policy formulation for some time to come. Moreover, in a number of countries, environmental deterioration has become so severe that what used to appear to be long-run problems have become short-run problems as well.

In providing an operational definition, it must be recognized that for any given system, one may wish to sustain more than one aspect of that system, and conflicts may arise. An approach to sustainability in one geographic area may conflict with or enhance sustainability in others. Serious discourse on the concept of "sustainability" without further specification of what is to be sustained, at what levels, over what geographic area, and without a clear notion of the link between sustainability objectives and other societal objectives is not possible.

For instance, if the goal is to sustain levels of consumption per capita and population is growing, growth in the output of consumption goods is necessary. Or, if the prices of inputs and outputs are changing, then sustaining the profitability of farming requires that the production system be continuously altered. The basic idea of sustainability becomes more dynamic, and sustainability becomes "sustainable development" — sustainability per se is not enough.

If the objective is sustaining overall aggregate well-being in individual countries, then a clear set of policy issues emerges. It may not be necessary, and may even be counterproductive, to insist on the sustainability of every component of a subsystem. Much of the debate appears to be overly concerned about the sustainability of particular components while ignoring substitution possibilities among the components of a system.

But one should not be excessively sanguine about the substitutability of natural resources and other inputs in production. Recognition of the uncertainty and potential irreversibility of tampering with natural systems has prompted calls for maintaining the status quo or even "rolling back" our interventions in the natural world. This argument is not without foundation but it must also be recognized that such an approach risks foregoing a large number of perfectly sustainable activities that greatly enhance human well-being.

In many respects, the weight given to uncertainty and irreversibility and the degree of aversion to the implied risks lies at the heart of much of the sustainability debate. This points to the need to identify possible irreversible activities and the associated indicators of impending irreversibility for different agroecological zones, production systems, and sociocultural situations.

Some Specific Issues

There are three basic areas of potential degradation and impending irreversible harm to natural and environmental systems that are central to the question of sustainable development of agricultural systems in the less-developed world: (a) areas experiencing rapid change, at a pace sufficient to outstrip the capacity of farmers and others to adapt, (b) areas under intense resource management resulting in environmental pollution, overreliance on exhaustible inputs, such as fossil-fuel energy sources, and overexploitation of renewable resources, such as irrigation water, and (c) marginal areas of low potential, such as mountainous areas, areas at the edges of plant ranges, or those with poor soils or climates.

The dual concerns of maintaining the resource base and increasing crop yields have led to the conclusion that most research attention should be directed to marginal lands and to technologies other than those of the Green Revolution. This "marginal-lands hypothesis" raises its own concerns. For one thing, it is predicated on the idea that future gains from favorable areas using Green Revolution technologies, or their predecessors, are limited. Although yield gaps for some cropping systems in favorable areas appear to be shrinking, it is certainly premature to presume that yield ceilings cannot be raised in the future. Moreover, simply maintaining existing yield potentials in more favored environments requires a continuous investment in maintenance research to combat the effects of pest, disease, and possible resource (e.g., soil and water quality) degradation over time.

The expanded reliance on manufactured, nonorganic inputs in intensified agricultural production systems is another area of concern. Abandoning the use of these inputs in the short term because of possible increases in future energy prices again seems premature and denies the prospect of sufficient technical change in input markets in the future.

Certainly the use of external inputs may cause pollution. But, the appropriate level of pollution is generally not zero. The costs of pollution must be weighed against the costs of pollution control and the foregone benefits associated with the activities that cause pollution. Moreover, lands vary tremendously in terms of the risk of pollution for any given level of inputs. It is possible to recognize the gains from applications of inputs on some lands, while restricting applications on others, even under the same cropping system. This kind of targeted approach represents a substitution of knowledge for environmental capital. Research is needed on the extent to which this substitution can be achieved across a variety of agroecological zones and cropping systems.

Progress towards building a sustainability perspective into agricultural research will be in the context of specific geographic areas, production systems, and resource concerns. While generic recommendations are difficult, a few do emerge: (a) efforts should be made to measure the economic costs and external effects of agricultural production so that prices of inputs and costs of production adequately reflect their full cost to society, (b) techniques should be developed to account for resource depletion in economic terms, (c) primary attention should be given to uncertainty and impending irreversibilities in determining priorities for action, (d) the generation and diffusion of improved management practices should be given more emphasis, and (e) monitoring capabilities need to be enhanced so that the status of the resource base can be assessed in a timely fashion.

trial pollution in industrialized countries, emissions are likely to rise in line with economic growth in the less-developed world. Furthermore, efforts directed at curbing the pace of forest clearance or the intensification of agriculture are unlikely to produce dramatic results in the near future.

As a consequence, it is more probable that an "adaptionist" rather than "preventionist" strategy will prevail in the near term. Such an approach would require the creation of institutions and policies that permit sustained agricultural growth while at the same time tackling the problems it causes — for instance, with more effective programs to manage the world's water resources. It will also require greater efforts to change current policies that encourage harmful practices to policies that take account of the wider public good.

However, many of the recent advances in productivity have been based on the availability of abundant supplies of cheap energy. As oil and gas supplies are likely to become increasingly scarce and more expensive in the next century, it is incumbent on research systems to develop alternative, energy-efficient production methods.

These concerns mean that research must place greater emphasis on developing new farming methods and land uses that act to sustain or enhance the natural resource base for agriculture.

A number of priorities can be identified in this connection. Perhaps the most pressing is to develop new environment-friendly chemicals and biological pest-control technologies and to develop new farming methods that will reduce soil erosion, salinization, and groundwater pollution.

Carrying out most of these changes will require better information on the causes and the extent of environmental damage. There is a serious lack of information available on the most basic issues, on the actual degree of soil erosion and the full extent of groundwater pollution and species loss, for instance. A comprehensive information system must be developed to document these and other problems, as well as their effects on human populations, including the health risks they pose and the limits they place on advances in welfare.

One of the high-priority issues in the next century will be the state of the world's water supply. Agriculture is a major user, as well as a major polluter, of water supplies. Water pollution has a serious impact on public health and agricultural production in many countries. Furthermore, climate change is sure to produce important changes in the distribution of and demand for the world's water supplies. A high priority must therefore be to enhance the efficiency of water use both in the long and the short term.

A final issue requiring urgent consideration is the effect on farmers' behavior of government interventions in farm commodity prices, such as price supports and subsidies, programs that directly promote or quantitatively limit production, and tax incentives. The task of research is to ensure that governments take into account the consequences for the environment of the actions that their policies may, and indeed do, induce.

While the past contributions of agricultural research to productivity gains and the improvements in living

Closing Comments

standards that followed have been impressive, the challenges that lie ahead are considerable indeed. There will be unprecedented increases in the demand for additional food and fibre production while the threats to even achieving, let alone sustaining, such levels of output in the face of a degrading natural resource base for agriculture loom large. Such threats appear as real for the more-favored, intensively cultivated production environments as they are for the more marginal areas.

There are unlikely to be any quick technological fixes. In fact, for the more immediate term at least, maintaining as well as enhancing past productivity increases is likely to come from the incremental gains arising from a whole array of new technologies and management practices. While individually less "newsworthy" than the Green Revolution technologies of the past, these sources of growth, when taken as a group, will nevertheless be just as real.

But to realize these output gains in a manner that preserves the environment will require a sustained commitment to national and international research endeavors. While many countries experienced a substantial growth in their research capacity in the 1960s and 1970s, a considerable number saw an erosion of their public-sector research capacity in the 1980s. Although privately sponsored research efforts are sure to grow in the future, the corollary is not necessarily to cut back on public-sector investments. In fact, the substantial growth in privately sponsored research in the US over the past several decades occurred in conjunction with a continued, albeit slower, growth in public-sector research investments.

To fully harness the potential complementarities and synergy between public and private research endeavors will require that more attention be given to each sector's comparative research advantage. In particular, the gains to researching improved agricultural management and production practices — those that will play a large role in realizing sustainable increases in agricultural output — are generally difficult to appropriate and likely to remain the domain of the public sector; so too are the more basic, pretechnology types of research that in turn lay the foundations for the privately sponsored applied and adaptive research programs of tomorrow. Failure to support and nurture today's research endeavors may well reap many unfortunate and undesired consequences in the not-too-distant future.