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Sustaining growth in agriculture: a quantitative review of agricultural research investments

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Abstract

Growth in agriculture depends on many things but one of the most important is investment in agricultural research. Decision making in the agricultural research policy area can only be aided by access to better information. This article overviews a recent endeavor to move policy dialogue beyond merely qualitative impressions towards a process that is underpinned with new and cogent data. The data used have been assembled at ISNAR in a manner designed to make comparisons both over time and between countries more valid than has been the case in the past. The comparisons thus possible reveal considerable diversity both between countries and between broad regional aggregations. Also illuminated here are issues related to the commodity orientation, capital and labor intensity, and size and scope of particular national programs.

Policy-makers are having to contend with unprecedently rapid changes in the market for agricultural science and technology services. In the 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, such as sub-Saharan Africa, and Latin America and Caribbean, investment in agricultural research stagnated or even declined. In addition, the level of development aid to less-developed countries stalled during the 1980s (OECD, 1989) while the small but significant share that was channeled to agricultural research is threatened by other demands. A reversal of these trends seems unlikely

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The research data reported here are largely from a study undertaken by ISNAR with assistance from the then Agriculture and Rural Development Department of the World Bank (Pardey, Roseboom and Anderson, 1991). The monetary values throughout this paper 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 taken from Summers and Heston (1988) and, for China, Summers and Heston (1991). The authors thank Hugh Quigley for his assistance in preparing this paper.

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in the near future and therefore 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 decline 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 stringencies, the demands being 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 also being called upon to broaden their research agendas and to 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 about the appropriate division of labor and problem focus between the national, regional and international centers that are yet to be resolved.

There are large variations across countries and over time in the level of investment in agricultural research. As a country's per-capita income grows, its support for agricultural research – as indexed by an agricultural research intensity (ARI) ratio that expresses research expenditures relative to agricultural output – tends also to grow. But there are offsetting tendencies, includ-

Table 1
Annual agricultural research personnel and expenditures, regional totals

Region	1961–65	1971–75	1981–85	Growth rate (%) [a]
Agricultural research personnel (full-time equivalents per year)				
Sub-Saharan Africa (43) [b]	1 323	2 416	4 941	6.8
China	7 469	11 781	36 335	8.2
Asia and Pacific, excl. China (28)	6 641	12 439	22 576	6.3
Latin America and Caribbean (38)	2 666	5 840	9 000	6.3
West Asia and North America (20)	2 157	4 746	8 995	7.4
Less-developed countries (130)	20 256	37 221	81 848	7.2
More-developed countries (22)	40 395	48 123	56 376	1.7
Total (152)	60 651	85 344	138 224	4.2
Agricultural research expenditures (millions 1980 PPP dollars per year)				
Sub-Saharan Africa (43) [b]	149.5	276.9	372.3	4.7
China	486.7	874.8	1 712.7	6.5
Asia and Pacific, excl. China (28)	316.7	651.5	1 159.6	6.7
Latin America and Caribbean (38)	229.1	486.6	708.8	5.8
West Asia and North America (20)	126.9	300.7	455.4	6.6
Less-developed countries (130)	1 308.9	2 590.5	4 408.7	6.3
More-developed countries (22)	2 190.7	3 726.3	4 812.9	4.0
Total (152)	3 499.6	6 316.8	9 221.6	5.0

Source: Most of this table is drawn from Pardey, Roseboom and Anderson (1991, p. 200), as are most of the data reported in this paper. The China data are from Fan and Pardey (1992).
Totals may not add up exactly because of rounding.
[a] Compound annual average growth rate between 1961–65 and 1981–85.
[b] Bracketed figures indicate the number of countries in the regional totals. The appendix to Pardey, Roseboom and Anderson (1991) indicates which specific countries were included in the regional aggregates.

ing one whereby agricultural research expenditures rise less than proportionately with agricultural output, due possibly to economies of size or economies of scope in research. In this paper we present a quantitative review of the global pattern of investment in agricultural research using a new compilation of data that serves to completely revise and update the data series reported by Evenson and Kislev (1975), Oram and Bindlish (1981) and Judd, Boyce and Evenson (1986). Our intention is 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.

1. Public investments in national agricultural research

1.1. Investment trends

Differences in patterns of agricultural growth are in large part the result of national differences in factor and environmental endowments and in the policies adopted towards agriculture and, more specifically, agricultural research. For two decades, up to the mid-1980s, global investment in public agricultural research increased substantially. [1] Between 1961–65 and 1981–85, the total number of public-sector agricultural researchers grew at an average annual rate of 4.2%. The number of researchers in less-developed countries increased by 7.2% a year, just over four times the annual rate in more-developed countries (Table 1).

In the period 1981–85, the less-developed countries employed 59% 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 and Caribbean, both of which have been struggling to contain soaring international debts. In fact, the 1976–80 to 1981–85 annual rate of growth in real research expenditures was only 0.7% for sub-Saharan Africa and 0.9% for Latin America and Caribbean compared with a more-and less-developed country average of 2.9% and 4.3%, respectively. Although spending on agricultural research increased faster in less-developed than in more-developed countries during the past two decades, the less-developed countries' share of total expenditure on research rose only to 48% from its 37% in 1961–65.

Of the less-developed regions, only in Asia and Pacific did annual growth in research expenditures 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.

1.2. 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 NARSs.

One reason for the relatively lower spending per researcher in less-developed countries is that, of late, the rapidly expanded university systems in these countries have produced many more graduates than previously. Many governments in less-developed countries insist that public bodies, including research systems, employ graduates, but then fail to provide adequate matching funds.

In the Asia and 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 are dominated by larger research systems that may well be able to realize economies of scale and scope.

[1] The global comparisons presented in this paper 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.

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 infrastructure 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 national research staff, and in part because of the above-mentioned budgetary crises.

1.3. Human capital

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 research degree (Table 2). If expatriate researchers are excluded from the calculation, no less-developed region has a share of researchers with a postgraduate qualification greater than 60%. For a significant number of countries it is even lower than 40%. 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.

Table 2
Nationality and degree status of agricultural researchers, 1981–85 average (%)

Region/country	Expatriates	Share of postgraduates [a]
Sub-Saharan Africa [a]	29	45
Asia and Pacific [b]	11	53
Latin America and Caribbean	2	51
West Asia and North Africa	18	27
Less-developed countries	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 for 1980 only.
[b] Does not include China and India, the two major NARSs in the region.

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 a more abrupt process 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% in the early 1980s. Making the plausible assumption that the numbers 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%.

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 and conditions in public agricultural research institutes are not competitive with other employment 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 or a mature research program. The contemporary systems of Australia and New Zealand, for instance, have apparently achieved significant successes with a high proportion of staff trained only to the BSc or MSc level, as did the U.S. system in earlier years. While certainly 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 may be of questionable relevance.

1.4. Commodity orientation

In less-developed countries, agricultural research is directed predominantly at crops. Based on a sample of 83 countries, 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.

There are some limited regional disparities in the share of resources devoted to a particular commodity orientation (Table 3). While such disparities are inevitable, given regional variations in the pattern of production, it has been argued by some that less research is devoted to fisheries and forestry than their reported economic importance warrants (see Mergen et al., 1988, on forestry research). In fact, the data – as shown in Table 3 – do not generally support this proposition. Research into forestry attracts more resources than its congruent share in agricultural output in all regions. In Asia and Pacific, and West Asia and 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.

Table 3
Regional congruence between agricultural GDP and research personnel, 1981–85 (%)

Region	Crops and 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 and Pacific, excl. China (10)	89.7	81.1	5.2	9.4	5.0	9.6
Latin America and Caribbean (20)	94.2	92.8	2.9	5.4	2.8	1.8
West Asia and 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

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 breakdown is based on regional samples that include a somewhat larger number of countries.

1.5. Factor shares

A major challenge for managers of research systems is to make the most effective use of available resources. 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 indications of magnitude based on a sample of countries, not as economic optima necessarily to be targeted.

The available data suggest that, in 1981–85, NARSs in less-developed countries on average devoted 19% of annual expenditures to capital investment, compared with 8% in the U.S. The higher share of spending on capital equipment by NARSs in less-developed countries supports the conclusion, also evidenced by their rapid growth, that most are in an expansionary phase. During this phase, not only must capital stock be replaced but additional capital stock must be acquired. The pattern of expenditures in the U.S., on the other hand, reflects that of a mature system, most of whose capital spending entails replacement of existing equipment. The emphasis in the U.S. 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 (Pardey, Eveleens and Hallaway, forthcoming).

The contemporary pattern of expenditure in less-developed countries mirrors that of U.S. 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. Capital (i.e., land, buildings, equipment, etc.) has claimed the same share of overall spending in U.S. research stations (about 8%) 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, may counterbalance this effect somewhat, but it is not likely that it will outweigh it.

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 spent an average of \$48,100 in constant 1980 dollars per researcher, compared with \$91,200 per researcher in the U.S. The contemporary level of spending per researcher in less-developed countries again appears to reflect the situation in the early years of the U.S. experiment stations. In fact, in the U.S., 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 one-third of original levels and did not recover until the 1970s – some 60 years later!

One of the major difficulties in making plausible cross-country 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 U.S. Looked at this way, the share of operating costs in recurrent expenditures in 1981–85 averaged 15% in less-developed countries.

After adjusting for cross-country price differentials, operating expenditures per researcher are also much smaller in less-developed regions than in the U.S. Agricultural researchers in sub-Saharan Africa, Asia and Pacific, Latin America and Caribbean, and West Asia and North Africa work with only 50%, 43%, 74% and 22%, respectively, of the operating resources provided to a U.S. 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 U.S. 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.

1.6. Size, scope, and spillovers

Since 1961–65, the average size of NARSs has more than doubled, from around 400 to 910 researchers, as has average expenditure per system. In less-developed countries the average size of NARSs has increased from 155 to 630 full-time equivalent researchers. Nevertheless, 95 of the considered 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 past two decades has diverged significantly.

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, certain activities can relate to improving crops or to 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 size 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 is that, when a system can create sufficiently strong economies of scope, these can, in turn, lead to economies of size across the whole range of its activities, even if such economies of size do not arise for some individual research programs (Baumol, Panzar and Willig, 1988). Of course, there can also arise diseconomies of scope, particularly among small systems that spread their limited resources across numerous 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 with the capacity to do little more than search and screening for suitable technologies. 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 necessarily 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, adapting spillovers from other research systems is most effective if they 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.

1.7. Research and productivity

Research is best 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 the benefits of research can still have an effect in increasing output for as long as 30 years after the research was initiated. To consider gains in agricultural gross domestic product (AgGDP) as a measure of the impact of contemporaneous research expenditure could thus be misleading. Differences in the quality of land and labor, and in the intensity of use of other inputs such as fertilizers and machinery, will influence output and so distort international comparisons of output that are measured only in terms of research.

In fact, all the more- and less-developed regions steadily increased their research intensities during that period (Table 4). 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.

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

Table 4
Agricultural research factor-intensity ratios

Region	1961–65	1971–75	1981–85
Agricultural research expenditures per economically active person in agriculture			
Sub-Saharan (37) [a]	1.7	2.7	3.1
China	1.7	2.5	4.1
Asia and Pacific, excl. China (15)	1.2	2.2	3.4
Latin America and Caribbean (26)	6.5	12.8	17.7
West Asia and North Africa (13)	4.5	10.5	14.3
Less-developed countries (92)	1.8	3.2	4.6
More-developed countries (18)	48.6	119.1	213.5
Total (110)	4.7	7.5	9.5
Agricultural research expenditures per hectare of agricultural land			
Sub-Saharan (37)	0.2	0.4	0.6
China	1.2	2.1	4.1
Asia and Pacific, excl. China (15)	1.0	2.1	3.6
Latin America and Caribbean (26)	0.4	0.7	1.0
West Asia and North Africa (13)	0.4	1.0	1.4
Less-developed countries (92)	0.6	1.1	1.8
More-developed countries (18)	1.8	3.1	4.0
Total (110)	1.0	1.8	2.5

All expenditures are in constant 1980 PPP dollars.
[a] Bracketed figures indicate the number of countries in regional totals.

be directed towards maintaining gains from earlier research rather than enhancing output levels per se. Recent estimates suggest that, in the U.S., around one-third of research expenditures are spent on maintenance, and it is probable that many less-developed countries devote at least as much proportional effort to such work (Adusei and Norton, 1990).

2. International investments in 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 some dozen supranational research centers. (Recently the number was enlarged to 18 but our discussion here refers to the original 13.) Ten of these centers have their headquarters in less-developed countries. Most 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. The goals were extended in 1990, 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.

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 show clearly different phases of growth: rapid expansion during the 1970s, slower growth during the 1980s, and apparent stagnation or even decline in the past few years.

The U.S. was the largest single donor to the CG, although both Europe and Japan increased their share of contributions during the 1980s. The World Bank acted as a balancing "donor of last resort," allocating its funds after other donor intentions were known. It lately has contributed 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 and 1988, sub-Saharan Africa accounted for 39% of the CG's core expenditures, compared with 26% to Asia, 21% to Latin America and Caribbean, and 14% to West Asia and 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 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 cereals research declined steadily to about 40%, of which rice research 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 around 20%. The remaining resources are allocated to noncommodity programs, including farming systems, food policy, genetic resources, and NARS capacity building. The recent expansion of the system has broadened the commodity coverage to include fisheries, agroforestry and forestry, and bananas and plantains. It may also eventually include horticultural commodities.

The recent reorientation of CG 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 application, improved water management and cultural practices, along with new crop cultivars that were particularly responsive to more intensified production regimes. While the dramatic contribution of these technology packages to increasing global food supplies is unquestioned (Anderson, Herdt and Scobie, 1988), 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 seeking to improve or maintain productivity of 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 more responsive areas towards the more marginal ones. Analyses of the type reported by Byerlee and Morris (1993) will be needed for guiding future investment policy in this regard.

Research on resource management will become more important as the need for continued increases in food production places an ever greater strain on the world's natural resources. The CG has taken the first step in this direction. Strategies on how best to include agroforestry and resource management concerns into its 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 (TAC/Center Directors Working Group, 1993).

3. Private investments in agricultural 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. As farmers use more purchased inputs 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 will grow. While there is a general perception that the private-sector has increased its participation in and funding of agricultural research, there are no available data to give an accurate quantitative or even qualitative perspective of these developments at the global, regional, and, in many instances, even country-level.

There are various reasons why these data are not readily available. Firms may feel their competitive interests are not well served by a full and frank disclosure of their R&D activities and so may be less than forthcoming in this regard. Even when such data are reported, there are genuine difficulties in identifying the R&D component that relates specifically to agriculture. This is particularly a problem for multiproduct firms in the chemical, pharmaceutical, biological and mechanical industries that pursue economies of scope by sharing research resources across a number of lines of research. Apportioning these R&D expenditures to a particular country in any meaningful way is also problematic, especially when dealing with multinational firms that centralize various aspects of their global or regional R&D operations.

Recent estimates by Pray and Neumeyer (1989) for the U.S. and Thirtle et al. (1991) for the UK suggest that private-sector investments in agricultural and food (i.e., largely post-harvest) R&D are substantial and at least as great as the public effort. Reliable global estimates of private expenditures on agricultural R&D are simply unavailable. Persley (1990, p. 48) reports that about 540 million dollars were spent worldwide by the private sector on agricultural biotechnology research in 1985, accounting for roughly 60% of the 900 million dollars spent on modern biotechnology research for agriculture in that year. This private-sector R&D figure is significantly larger than the 36 million dollars Pray and Echeverría (1991) estimate was spent annually by multinational companies on all types of agricultural (including post-harvest) R&D in less-developed countries during the latter half of the 1980s. Taken together these figures suggest that an overwhelmingly large share of private-sector spending on agricultural R&D occurs in the more-developed countries.

The data reported by Pray and Echeverría (1991) support this view. During the mid-1980s, spending by U.S. firms on R&D in the food and agricultural sectors was around 2.4 billion dollars per annum (with about 58% of this total going to agriculture). Comparable figures for the UK and France are 530 million and 270 million dollars, respectively. Much of the privately sourced funds for agricultural R&D in the less-developed regions of the world comes from Latin America and Asia and, according to Pray and Echeverría (1991), it is concentrated in a few large countries such as Brazil, Mexico, Argentina and India.

Our understanding of the scale and scope of these private-sector efforts is, unfortunately, woefully inadequate. The recent and careful efforts by Falconi (1992, 1993) to compile time-series data on private-sector, agricultural R&D expenditures in Ecuador and Colombia are quite revealing in this respect. These new data show that, in both countries, private-sector spending on agricultural R&D grew much more rapidly than publicly sourced expenditures during the 1980s. By 1991, the private sector accounted for 37% of total agricultural R&D expenditures in Colombia (compared with 22% in 1970) and in Ecuador the private-sector share is now 27% (up from 19% in 1986). To the extent these developments are representative of the situation in other Latin American (and perhaps some Asian) countries, they call for a radical rethink of the roles of the public-sector research agencies in these regions.

Having said this, however, there are still many countries, especially in Africa, where the low level of purchased inputs in agriculture limits the size of the derived market for privately produced agricultural technologies. This situation is likely to continue for some time to come. Nevertheless, 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 incentives 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.

4. Political and financial support for agricultural research

A fundamental task facing NARSs is to win public support for research and translate it to 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, that ultimately tax agriculture and accelerate the transfer of resources from the sector. These same policies, in part by undervaluing the sector-specific assets in agriculture (e.g., land, irrigation facilities, etc.), can also lead to an underinvestment in agricultural research and the 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 present brief (Gardner, 1990; Roe and Pardey, 1993; Alston and Pardey, 1994). Rather, the aim here is to present some 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. [2]

Table 5
Agricultural research-intensity ratios by region and income group, total weighted average percentages (%)

Region/income group [a]	1961–65	1971–75	1981–85
Sub-Saharan Africa (37) [b]	0.26	0.42	0.49
China	0.42	0.40	0.41
Asia and Pacific, excl. China (15)	0.14	0.22	0.32
Latin America and Caribbean (26)	0.30	0.46	0.58
West Asia and North Africa (13)	0.28	0.50	0.52
Less-developed countries (92)	0.26	0.34	0.41
More-developed countries (18)	0.96	1.41	2.03
Low (30)	0.25	0.30	0.37
Lower-middle (28)	0.24	0.35	0.40
Middle (18)	0.25	0.46	0.57
Upper-middle (18)	0.27	0.44	0.55
High (16)	1.08	1.57	2.23
Total sample (110)	0.48	0.63	0.71

[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.

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 agricultural gross domestic product (AgGDP). 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 5). This apparent difference 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

[2] For an earlier version of these data, see Pardey, Kang and Elliott (1989).

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, one-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 (Echeverría, 1990). This fact, and the gap in investment compared with more-developed countries, has led some authorities to conclude that many less-developed countries under-invest 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 (World Bank, 1981).

Research-intensity ratios are useful to policy-makers 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 to below 20%, for example.

The data presented in Table 6 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 2.7% 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.

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,

Table 6
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 (12)	0.3	0.2	0.2
Total sample (70)	0.5	0.4	0.4

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.

consumers and taxpayers) in relation to alternative policy instruments, be they investing in rural public goods such as agricultural research versus taxes, subsidies and production quotas (Alston and Pardey, 1994). In the absence of available case-by-case data, the macro-level figures in Table 7 are suggestive of some of the political economy forces at work here.

While total government spending on agriculture, indexed over the agricultural population, increases dramatically by a factor of 85 times, from around $21 per capita in the low-income countries to $1800 per capita in the high-income countries, there is only a corresponding 8-fold increase in agricultural spending indexed over the total population. 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, 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. Modelling and quantifying governments' incentives to invest in rural public goods such as research is necessary but far from sufficient to develop policies that help sustain support to public-sector agricultural research.

Donor support. While funding for agricultural research is only a small part of international development aid programs, it constitutes a significant contribution to the financing of numerous less-developed NARSs. Aid from donor countries or organizations is particularly vital for countries where high levels of international debt and an

Table 7
Public spending per capita on agriculture and agricultural research

Income group [a]	Government expenditure on agriculture			Agricultural research expenditures		
	1971–75	1976–80	1981–85	1971–75	1976–90	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	12.4	19.8	26.5
High (15)	1338.2	1423.1	1801.0	91.8	113.2	140.6
Total	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
Lower-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	93.0	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

All data represent simple averages across all countries in each income class and are expressed in constant 1980 PPP dollars.
[a] Countries assigned to income classes based on 1971–75 per-capita GDP average 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.

inadequate tax base make it virtually impossible for the national government to adequately support a viable agricultural research program.

There is a serious lack of data available on precise levels of donor support to NARSs. What available data there are, are difficult to standardize given the disparate reporting methods used by NARSs as well as donors. Figures from donor countries and organizations for the period 1981–85 put contributions to agricultural research at an average of $658 million a year, which amounts to a very modest 1.9% of total official development assistance to less-developed countries. Based on data from the NARSs, donor contributions in that period amounted to only about $355 million a year. This discrepancy can probably be explained by the fact that NARSs commonly underestimate the full extent of contributions they receive. In estimating donor support, NARSs, quite understandably, often exclude payments in kind, such as the salaries and expenses of expatriates working for them, which can be a substantial element of aid contributions. It is also difficult to compile accurate figures on the amount of aid to a research system when it is given as part of a wider package of aid that is distributed through the country's national government.

The available data suggest that, in real terms, donor aid to NARSs has fallen since 1980 as overall levels of development aid have stood still. The World Bank accounts for around 25% of donor funds applied to agricultural research in the less-developed world, but the Bank's support for individual national research endeavors declined during the 1980s. Moreover, this support is concentrated in just a few NARSs. Of the $817 million it allocated to strengthen less-developed NARSs during the period 1981–87, two-thirds went to only six projects.

The levels of external funding to national systems vary enormously, from none in Venezuela and South Korea to 85% in Tuvalu. Sub-Saharan Africa had the highest rate of donor funding, receiving on average 35% of its expenditures from donors. NARSs in the Asia and Pacific region received an average of 26% of their funding from donors. The levels of donor support to NARSs in Latin America and Caribbean, and West Asia and North Africa were much lower, 7% and 11%, respectively.

5. Concluding observations

While the past contributions of agricultural research to productivity gains and the improvements in living 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 (Pingali, 1994).

There are unlikely to be any quick technological "fixes" to addressing these concerns. 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 (Byerlee, 1994). 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 endeavors 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 U.S. 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 improvements 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.

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