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Warren E. Kronstad Honorary Symposium

The Role of Public Agricultural Research in International Development

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1. Introduction

It is a great pleasure for me to participate in the W.E. Kronstad Honorary Symposium. I have known of Warren's work for more decades than either of us might wish to admit, and in the past few years drew closer as I served as USAID project manager for the Spring x Winter Wheat Project. My great professional respect has come to be matched by great personal respect. Warren has indeed made a significant difference in Oregon, the United States, and the world.

My assignment as part of the Symposium honoring his contributions is, as I have interpreted it, to say something about the role of the public sector in stimulating agricultural and ultimately international economic development. I will focus principally on public agricultural research, the sector in which Warren has spent his career, in the context of serving the developing countries of the world.

This is not a new topic, and portions of it have been touched on in many talks and papers. But it is broad and complex, and continually evolving. There are not many introductory treatments that are both comprehensive and current. And few are written from the perspective of someone with experience in the public system. This Symposium provides an opportunity for me to try to respond to this challenge.

The subject is not easily summarized in a few pages. I have attempted to tackle it in a two-stage process: a summary type text backed up by fairly extensive notes, documentation, and suggestions for further reading. While portions of the text will be familiar to some readers, other portions, particularly many of the notes and references, may be less well known. I hope that this approach will provide something useful for a wide spectrum of readers.

2. Agriculture and International Development

The purpose of development, as I see it, is to improve human welfare or the human condition. I am thinking of welfare in the same terms as my dictionary: (a) health, happiness, and general well-being; and (b) prosperity. Just as there are several components of welfare, there are several paths to its betterment. In terms of government programs, three components particularly come to mind: economic development, health improvement, and the betterment of education. In the developing countries, agriculture is the principal source of livelihood and offers a key means of promoting economic development and improving the nutritional side of health.

Agriculture in this context is defined as including the production of food and non-food products and the utilization and preservation of natural resources (including soil, water, and forestry). Food products, which accounted for about 95 percent of the value of agricultural production in the world (excluding fish and forest products) in 1997, play an important role in: (a) the economies of families and society, and (b) the nutritional status of individuals. Non-food agricultural products, most notably cotton, followed by tobacco, wool, coffee, tea, and rubber, clearly play an economic, if not nutritional, role in society. Natural resources are linked to agricultural production, but in the case of forest products also may have some economic value.

In view of its importance, it is logical to focus the bulk of our attention on food. Food production is a major source of income and employment and has spin-off benefits for local communities. Food processing and marketing also is of major importance, especially in more developed countries. Food purchases represent a major expenditure, especially in the poorest areas of the world, reaching 50 percent or more (60 to 80 percent in some cases) of disposable income. Food obviously is the major force in determining nutritional status, which in turn can influence human health, learning (cognitive skills), productivity, and well-being. Thus, anything that materially affects the supply, availability, and access to food is of major importance to society. This seems like a simple and obvious point, but it has eluded many governments and political leaders in both developed and developing countries.

The result has had both visible and less visible manifestations. The extreme and most visible cases, aggravated by civil crises, are famine and critical food crises, which appear in headlines and which prompt expensive and short-term food aid programs. Less obvious but more critical in terms of numbers are the large number of individuals in the developing world, currently estimated by FAO at 828 million, who are chronically undernourished. FAO recently reported that 17 countries have severe food shortages, leaving their populations with severely low energy intake, not to mention other nutritional deficiencies. Recent press accounts have highlighted extreme problems in Cambodia, North Korea, and Somalia.

UNICEF reports that more than half of the almost 12 million children under 5 who die in developing countries each year from preventable causes are victims of malnutrition. They also report that vitamin and mineral deficiencies are estimated to cost some countries the equivalent of more than 5 percent of their gross national product (GNP) in lost lives and disability. Less visible is the opportunity cost, the opportunities missed, when economic growth does not obtain the levels that it might due to a neglect of agriculture.

Agricultural development is a long-term process and is not always the answer to the more severe short-run problems of nutrition brought about by, say, civil or natural disasters. But it can play an important role in helping countries avoid these problems or in reducing their severity. More significantly, it can lay the basis for economic development and the improvement of lives of a much broader sector of society.

3. Agricultural Research and Development

Agricultural research is the linchpin of agricultural development. It generally is a necessary, but certainly not sufficient, condition. It is the key to increasing productivity, which is at the heart of

the development process. But to be adopted and prove effective it must be accompanied by a host of other factors and forces.

A. Scope of Agricultural Research

Agricultural research encompasses many forms of science, principally biological and physical science, but also social and economic science. Agricultural science, to the extent that it exists, is a mélange of many forms of knowledge that commonly are brought together in research institutions or research funding organizations that have an agricultural focus. Boundaries are primarily professional and probably are diminishing. As Peter Doherty, a Nobel Prize laureate, recently has noted: "The current reality is that all science is convergent, and the categories do not much matter."

Another way of looking at the components of agricultural research is to think of its three main functional components: science, technology, and policy. Science is the basic stock of knowledge, the mother lode. Technology is the application of science to some productive purpose. Policy, inter alia, provides the framework for the conduct and application of research in science and technology. Research is needed to expand our knowledge of science and to develop useful technologies and improved policies.

B. Institutional Components and Effect on Society

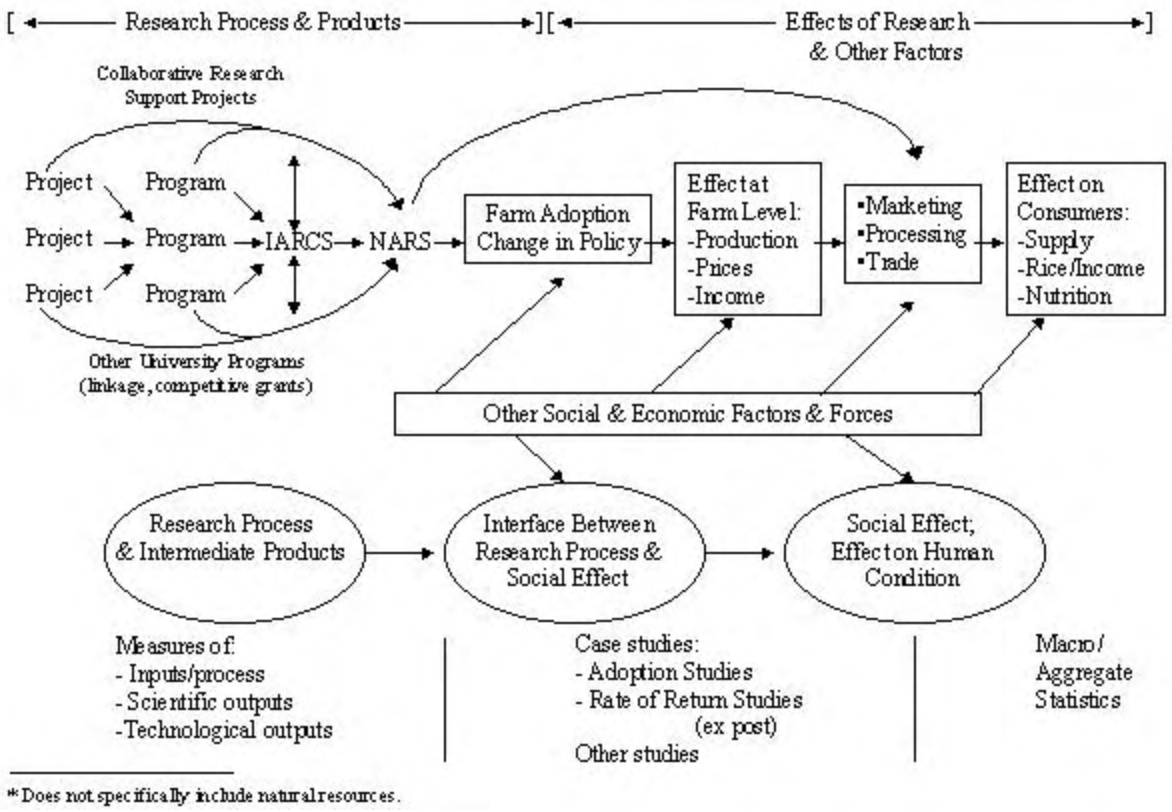
The key components of the international agricultural research system are: (1) research institutions in developed countries; (2) international agricultural research centers (IARCs); and (3) research programs in the developing countries. The country programs take a variety of forms and may be in the public and private sectors. USAID, to some degree, supports public programs in all three areas (further details will be provided in Section 5). Other bilateral and multilateral donors have similar activities.

The relationships between these programs and the chain of events, which takes place in terms of their interaction with society, are summarized from a USAID perspective in Figure 1. As noted, the research structure is outlined in the left side of the diagram, while the subsequent process that leads to the ultimate efforts on society is depicted on the right side.

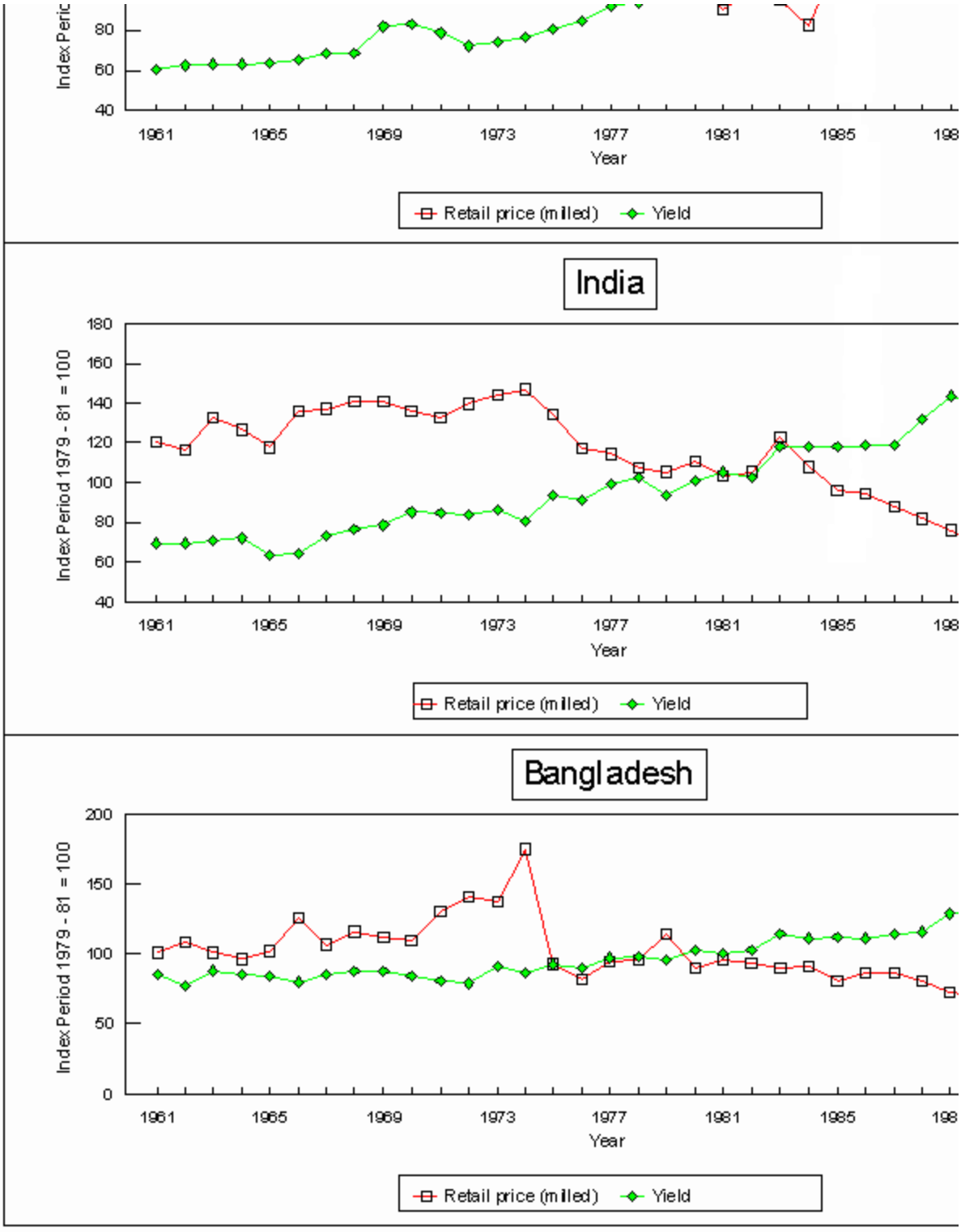
Clearly, research is just the first step in the process depicted. The products of research must be adopted, at first on the farms, but also, where relevant, by the marketing process. Adoption of output-expanding technology will increase yields and production, reduce farm prices, probably increase the income of early adopters (it may well not increase the income of late adopters because of lower prices), and stimulate local employment. The effect on consumers is more generally positive: the increased supply and lower prices (see Figure 2) are equivalent to an increase in income and normally will lead to increased purchases and improved nutrition among the poor (the nutritional effect may be less pronounced at higher income levels). The overall benefits to consumers may exceed those to producers. All of these effects in turn have positive influence on the local economy.

Figure 1

International Agriculture Research and Its Effects on Society: Structure and Measures*



* Does not specifically include natural resources.



Note:
Retail prices deflated by consumer price index for country.

Sources:
Yields: FAOSTAT, April 1998.
Prices: Calculated from data provided in World Rice Statistics, 1993-94, IRRI, 1995.

The social returns to this process generally are quite high. Many economic studies have been made of the rates of return to agricultural research. A recent summary of 294 studies, covering 1,858 research programs, revealed that the estimated rates of return for research averaged 88 percent. Not every research project falls into this category; some are clear failures and the impact of some may await a long incubation process (such as was/is the case with quality protein maize or with much natural resources research). With the tightening of public funding for research, increased effort is being given to documenting the effects of research, especially at the international level.

4. Relative Roles of Public and Private Research

The traditional distinguishing characteristic between the public and private sectors is the nature of the product they produce. The public sector focuses on public goods that are freely available to all. The private sector produces proprietary products that are available to those who purchase them. Generally, the public sector has been seen as the source of both basic and applied research and the private sector as a source of applied research. But the real world situation is more complex and is in the process of shifting.

A. Public Research

The key players in the public sector at the national level, universities and government research organizations, have somewhat different positions in developed and developing nations. Universities generally play a much more important role in research in developed than in developing nations, while government research units are relatively more important in developing countries. The U.S. model, which combines teaching, research, and extension at state universities, is not so prevalent in developing countries. Hence, research in developing nations has tended to be divorced from teaching and extension or outreach. The structure of governmental agricultural research has changed rather significantly in some developed nations in recent years, although not yet in the United States, and may be modified in others in the future.

The key players at the international level are the IARCs, most of whom are sponsored by the Consultative Group on International Agricultural Research (CGIAR). They produce international public goods in cooperation with all kinds of public research organizations at the national level. The IARCs draw from and utilize the scientific resources in developing countries and conduct their own research, generally in collaboration with research groups in developing nations. The IARCs also provide some training for developing country scientists and technicians, and conduct some participatory research with farmers.

These national groups in developing nations, however, often are not in very strong condition and extension or outreach programs may be weak. External assistance, which played a big role in providing support, is thought to have declined in many countries (this certainly is true of USAID; see Table 3). Moreover, public support at the national level often is weak or declining. And even where staffing levels are maintained, funding for research support, equipment, and facilities frequently is lagging. We often talk of a global agricultural research network, but the

components, especially at the developing country end, are becoming frayed. Thus, when IFPRI reports that "Developing countries now account for more than half of all global, public R&D investments," we have reason for concern.

B. Private Research

The private sector, defined here as the business community, plays a major role in agricultural research in developed countries, accounting for half or more of the total in the U.S., and has recently stepped up its investments in biotechnology research. The private sector is, however, much less important in the research arena in developing countries. The reason is simple: there is much more money to be made in developed countries with their more advanced forms of agriculture and their more highly developed systems of intellectual property rights, related policies, and infrastructure.

Clearly, the major interest of the private sector is a profitable product. In the past, this has largely led to concentration on inputs such as machinery, farm chemicals (fertilizers, pesticides), and seeds. With the increased emphasis on biotechnology, the nature of the last two categories is changing. The traditional definition of a profitable product is shifting, and industry is getting more involved in high-tech research. This new emphasis has blurred the traditional model of having basic research carried out in the public sector and applied research in the private sector, especially in the area of molecular biology and involving DNA. The private sector, however, is less active in other areas such as plant biology, physiology, or chemistry. In any case, this changing pattern applies much more to developed than developing countries.

One important area where the private sector has played little role is in research, which would lead to the development of improved public policies, such as is carried out by IFPRI or universities. But even here, the situation is changing to some extent. The increased involvement of the private sector in biotechnology has raised the importance of public policies relating to intellectual property rights and food safety. The agenda for policy research is being modified, and in a way that will emphasize the need to interact with the private sector. While the policy problems in the case of biotech are most notable in terms of the developed countries, they will continue to overflow into the developing countries.

C. Interactions

There is a considerable and probably increasing amount of interaction between the public and private sectors. Herdt recently has noted six forms of special relationships being pursued by private companies with public sector researchers. Some of this interaction involves complementarities, and some presents complications. And in either case, some gaps may remain.

Complementarities can benefit both parties. The private sector has long made free use of the basic or applied research done in the public sector (the seed industry is a case in point) or has paid to have various types of research carried out by universities. The reverse, public research benefiting from research by the private sector, perhaps has been the case less often, but this may be changing. The public sector now may be increasingly able to buy or borrow some research products or processes developed by the biotech industry for use in their own programs. In addition, the public sector in some cases may be the recipients of fairly unrestricted grants for research or research facilities. Public-private consortiums also are being developed, and the

philanthropic side of the private sector conceivably could play a larger role. All of these examples, however, are found far more often in developed than in developing countries.

Complications abound in the area of intellectual property rights (IPR). Genetic resources, which used to be considered the "heritage of mankind," increasingly are tied up in IPR and nationalistic issues. The same is true of biotechnology more generally. And there can be substantial public relations problems for both public and private sectors when they face groups or individuals who are opposed to at least some forms of biotech, or are concerned about its food safety dimensions.

Although increased interaction will, even in the face of difficulties, likely be the prevalent model, there probably will be some areas where gaps will persist. The private sector is unlikely to ever show much interest in doing research on self-pollinated crops such as wheat or rice (except in their hybrid variants), and some new innovations, even one as striking as quality protein maize, may go neglected by the private sector if it does not foresee a significant market. Similarly, the private sector also is not likely to do much research on minor crops or natural resource management.

Overall, the public and private sectors, and ultimately society, benefit from each other. The challenge is to maintain the public side of this balance in both developed and developing nations.

5. Major Forms of International Public Research

There are many international agricultural research efforts sponsored by many donors around the world. I will confine my remarks to a brief summary of these sponsored by USAID. (Several other U.S. government agencies, including USDA, EPA, and NOAA also support international research activities that directly or indirectly relate to agriculture.)

A. Major Types and Funding Patterns

Over time, there have been two major types of research efforts in USAID: (a) funding of individual country research programs by the regional bureaus; and (b) funding of multi-country research programs by a central bureau (presently the Global Bureau). In some cases, there has been a cross-over: regional bureau funding of activities administered by the central bureaus or the programs it sponsors. Research projects presently funded by the central bureau are of three main types:

- IARCs. Principally under the aegis of the CGIAR.
- CRSPs (Collaborative Research Support Programs). All managed by U.S. universities.
- Other. Generally involving U.S. universities.

The specific IARC and CRSP centers and programs are listed in Table 1 and Table 2. The most relevant project in the Other category is titled Agricultural Biotechnology for Sustainable Productivity (ABSP); it is managed at Michigan State University and involves a consortium of public sector institutions and private companies in the U.S. and developing countries.

The USAID funding patterns for these programs from 1956 to 1996 are summarized in Table 3. It will be seen that for the years listed, there was a gradual rise to an overall peak of nearly $218 million in 1986, and then a sharp drop to $73 million in 1996, a decline of two-thirds. The decline was largest, in dollar terms, for research sponsored by the regional bureaus and the CGIAR. As a proportion of the total in 1996, regional bureaus represented 42.3 percent, followed by the CGIAR, CRSPs, and others. Since 1996, the CGIAR contribution has risen to about $26.4 million.

B. Expanding CGIAR Linkages With U.S. Researchers

We long have felt that both the CGIAR centers and U.S. researchers would benefit from closer ties. There has been, as documented by Collins, considerable interaction at the scientist-to-scientist level, often involving joint training of graduate students. Some centers have had contracts with U.S. institutions. Oregon State, for instance, long has maintained close relations with CIMMYT through the Spring x Winter Wheat program. But these ties largely have been ad hoc and seldom have been encouraged in any formal way.

A few efforts have, however, been made to make greater use of U.S. scientific capacity. The first, initiated in 1986, was informally called the constraints program and was oriented to scientific problems identified by the IARCs. U.S. universities were invited to make proposals for work on selected constraints and were selected on a competitive basis. Altogether, 32 grants were made involving 24 U.S. institutions and 12 centers before funding ran out after a few years. Nothing more was done until 1998, when the availability of some resources ($2 million) from the Africa Food Security Initiative made possible the establishment of a very similar activity: a Competitive Grants Program. Eight constraints were selected involving seven U.S. universities working in cooperation with seven IARCs (including one that is not a member of the CGIAR). This is a promising program, but future funding is uncertain.

Another action involving the CGIAR centers, which didn't require any additional funding, was to make use of what is called a soft earmark. Starting in 1997, the centers were asked to set aside 8 percent of the grant they received from USAID (or about $2.1 million in total) for research linkages with U.S. universities. The centers were entirely free to select the area of work and the universities. This led, as expected, to smaller programs than were established under the constraints program, but many more of them and with many universities (more than 40 in 1997).

Table 1. International Agricultural Research Centers Supported by USAID, 1997.

Center	*Headquarters*	*Founded*
CGIAR		
CIAT-Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)	Colombia	1967
CIFOR-Center for International Forestry Research	Indonesia	1992
CIMMYT-Centro Internacional de Mejoramiento de Maiz y Trigo (International Center for the Improvement of Maize and Wheat)	Mexico	1966
CIP-Centro Internacional de la Papa (International Potato Center)	Peru	1971

ICARDA-International Center for Agricultural Research in the Dry Areas	Syria	1977
ICLARM-International Center for Living Aquatic Resources Management	Philippines	1977
ICRAF-International Center for Research in Agroforestry	Kenya	1977
ICRISAT-International Crops Research Institute for the Semi-Arid Tropics	India	1972
IFPRI-International Food Policy Research Institute	United States	1975
IITA-International Institute of Tropical Agriculture	Nigeria	1967
ILRI-International Livestock Research Institute	Kenya	1995
IPGRI-International Plant Genetic Resources Institute	Italy	1974
IRRI-International Rice Research Institute	Philippines	1960
ISNAR-International Service for National Agricultural Research	Netherlands	1979
IWMI-International Water Management Institute	Sri Lanka	1984
WARDA-West African Rice Development Association	Cote d'Ivoire	1970
Non-CGIAR		
IFDC-International Fertilizer Development Center	United States	1975

Table 2. Collaborative Research Support Programs Sponsored by USAID, 1997.

CRSP	*Year of Inception*	*Management Entity*	*Number of Collaborating U.S. Institutions*[1]
Bean/Cowpea	1980	Michigan State Univ.	12
BASIS (Input Systems)[2]	1996	Univ. of Wisconsin	15
Integrated Pest Management (IPM)	1993	Virginia Tech.	10
Peanut	1982[3]	Univ. of Georgia	9
Pond Dynamics/Aquaculture	1982[3]	Oregon State Univ.	9
Small Ruminants	1978[4]	Univ. of California, Davis	10
Soil Management	1981[3]	Univ. of Hawaii	5
Sorghum/Millet (INTSORMIL)	1979	Univ. of Nebraska	4
Sustainable Agriculture (SANREM)[5]	1992	Univ. of Georgia	9

Postharvest (CASP)[6]	1993	Mississippi State	3
West Africa Natural Resource Management InterCRSP[7]	1995	Virginia Tech.	

1. In addition to Management Entity. A number of developing country institutions are involved as well.
2. Broadening Access and Strengthening Input Market Systems.
3. Reorganized in 1995/96.
4. Reorganized in 1998.
5. Sustainable Agriculture and Natural Resource Management.
6. Postharvest Collaborative Agribusiness Support Program (not formally a CRSP but very similar).
7. Composed of seven CRSPs.

Source: *Global Research for Sustainable Agriculture,* CRSP Council, 1997, 52pp. (Copies available from Office of Agriculture and Food Security, EGAD, Global Bureau, USAID.)

Table 3. USAID Expenditures on Agricultural Research, 1956-1996.

Year	**Central Bureau**				**Regional Bureaus**	**Total**
	IARCs	CRSPs[1]	Other	Total		
	- millions of dollars -					
1956	-	-	0.10	0.10	0.90	1.00
1961	-	-	-	0.11	1.13	1.24
1966	-	-	-	.87	7.94	8.81
1971	3.00	-	2.60	5.60	20.95	26.55
1976	15.70	-	9.39	25.09	44.67	69.76
1981	36.00	8.30	13.10	57.40	87.51	144.91
1986	48.30	14.20	24.52	87.02	130.68	217.70
1991	43.30	17.80	19.38	80.48	115.31	195.79
1996	22.45	17.45	2.03	41.93	30.85	72.78
Change 1986-1996	-25.85	+3.25	-22.49	-45.09	-99.83	-144.85
	-53.5%	+22.9%	-91.7%	-58.8%	-76.4%	-66.6%

1. Other, more recent, internal data place the CRSP totals as follows: 1981, 10.95; 1986, 15.45; 1991, 16.94; and 1996, 17.47. This would place the change from 1986 to 1996 at +2.02 or +13.1%.

Source: Gary Alex, USAID and Agricultural Research; Review of USAID Support for Agricultural Research, World Bank, ESDAR, 1997, pp. 60-63.

Feedback on the program from both the IARCs and the centers has been excellent and it is planned to continue the program.

The competitive grants and linkages programs complement each other nicely, and it is to be hoped that funding can be found to continue the grants program.

C. Types of Relationships With Developing Countries

USAID-sponsored research programs with the various research entities in developing countries generally encourage or involve collaboration. The exact mode varies somewhat between the IARCs and the CRSPs. The IARC research nearly always is carried out in developing nations, in some cases through networks of national programs (this is particularly true in Africa). CRSP research usually has a higher proportion carried out in the U.S., but with a strong tie to developing countries (the target proportions are 50/50, but this may not reflect the actual allocation of funds due to cost differences). There recently has been some interest in encouraging more Center involvement in participatory research, but there are limitations on how far relatively small international research groups can go in this direction.

While the emphasis is on longer term research activities, the programs also may be of value in a shorter time span or in ways not initially contemplated. For example, IRRI has helped replenish the genetic resources in Asian nations which had been lost to wars or other civil problems. In the 1980s, for example, seeds of lost Cambodian rice varieties, which were part of the IRRI genebank, were returned to the country; following further improvement, eight varieties recently have been released. A variant of this process, known as "Seeds of Hope," has been carried out in Africa for several years; it initially proved to be very successful in Rwanda and has expanded to other nations, including, most recently, Honduras and Nicaragua. In Honduras, it was reported that a digital atlas of the country compiled by CIAT shortly before the arrival of Hurricane Mitch for agricultural and environmental planning may "play a key role in restoring the country’s agricultural capacity," and that this kind of technology is "likely to play an increasingly important role in disaster relief in the future." The Office of Foreign Disaster Assistance in AID’s Bureau of Humanitarian Response is very supportive of efforts of this nature.

D. Changing Motivations

The motivation for providing longer term assistance to agricultural development and agricultural research in USAID has changed somewhat over time. In the early years, it was very much humanitarian. This interest still remains to some extent but, perhaps paralleling broader changes in the climate for foreign assistance, has tended to include a greater mutual interest component.

Mutual interest essentially means doing well by doing good and has both direct and indirect aspects. Agricultural research, as we have noted, helps stimulate economic growth in developing countries, which helps expand the market for U.S. agricultural exports. It also produces technology that sometimes can be used in U.S. agricultural programs to increase our own productivity. Cummings has referred to this process as reverse technology flow.

During the 1960s, the agricultural research program in USAID was held back by Congressional concern that it might lead to increased competition. Thus, work on basic food crops such as wheat and rice was constrained until 1968. During this period, there also were increased benefits of growth; the arguments and evidence were summarized in a speech prepared for the 1970 National Agricultural Outlook Conference. This and similar efforts did not immediately turn the situation around but did help lead to a substantial change in view over time.

It also began to become apparent during the 1970s that the United States was starting to accrue substantial benefits from the development of the semi-dwarf high-yielding varieties of wheat and rice. This led me to develop a detailed bulletin on the subject in 1980. I continued to follow this matter in some subsequent reports on the high-yielding varieties. The very significant economic impact was evaluated more formally in an IFPRI report in 1996.

While mutual benefit can be demonstrated for both the IARCs and the CRSPs, it perhaps has worked more to the advantage of the CRSPs (Table 3). The CRSP program was established with a direct eye to mutual benefit, and the location of project leadership in the U.S. has led to a strong support from the local Congressional representatives. The CGIAR IARCs, being located overseas (except for IFPRI, which is in Washington), do not have this advantage; but occasional Congressional contacts reported to us suggest there is strong interest in the benefits of center work to the U.S.

One might bemoan the relative decline of humanitarianism as a motive, but the mutual interest concept probably provides a stronger domestic basis of support for international research, as long as the benefits to developing countries continue to remain a key point of focus.

6. Major Constraints in International Public Research

The constraints on international agricultural research are much the same as those facing public agricultural research around the world and agricultural development more generally. They are primarily financial and can be traced to a number of causes. In addition, Mother Nature continues to throw up challenges of a biological nature. And man has worsened the situation through overuse and abuse of natural resources.

A. Overall Funding Patterns and Some Comparisons

Funding for international agricultural development, both by multilateral and bilateral assistance organizations and by developing countries themselves, has been shown by IFPRI to have declined from the early 1970s to 1990. The pattern undoubtedly has persisted since. Agricultural research has not been hit so sharply, but its rate of growth for public research has been reduced

in both developed and developing countries, as is shown in the following data recently reported by IFPRI.

Region	1971-81	1981-91
Developed	+2.7%	+1.7%
Developing	+6.4%	+3.9%

The overall decline in rate of growth was about the same for both regions; it probably has continued. The authors noted that "Some countries (especially in Africa but also in Asia and Latin America) have seen a contraction in real public support for agricultural R&D."

The situation for agricultural research in the United States in recent years has been more mixed. At the federal level in 1999, which turned out to be an exceptionally good year for research, the overall research budget will rise by $4.1 billion to $80.2 billion. Defense R&D accounts for 52 percent (or $41.8 billion) of this total, and non-defense R&D 48 percent (or $38.3 billion). Non-defense R&D will rise by $2.7 billion or 74 percent; much of the increase is in the health area which will grow 14 percent. USDA, which accounts for 4.3 percent of the non-defense area, will rise by $103 million or 6.6 percent. However, $23 million, or 22 percent, of this total is emergency funding to develop ways to destroy crops of illegal drugs. Also, Congress blocked funding for a new competitively awarded agricultural research program that was authorized in June 1998 ("...when it came time to pay for these initiatives, Congress balked"). USAID funding for all research remains at a relatively minuscule $150 million.

Even these levels are dwarfed by more general public expenditures on the military in both developed and developing nations. These have been estimated by one source to total more than $700 billion in 1994, or 3.0 percent of GNP. In the U.S., larger military and intelligence budgets may be on the way. The Pentagon has requested a $12 billion increase in next year’s budget and a $110 billion increase over the following 6 years. The CIA, after stating that it "will no longer be relevant" without an infusion of money and talent, recently received a supplemental appropriation of $1.8 billion and "will seek billions more" in future budget requests.

Military expenditures may, of course, cut close to the bone in the poorer nations. India spends twice as much on its military as it does on education and health programs, while Pakistan spends four times as much; expenditures on nuclear weapons research recently have been noted to be in sharp contrast with widespread poverty and social needs. In Ethiopia, according to one recent account titled "Food Frees Money for Arms," the country received food aid worth $90.2 million from Russia while spending $150 million for military equipment from Russia.

Obviously, agriculture, despite its basic importance, does not begin to compare with the appeal of other forms of public research or other forms of public expenditure (some of which, one might

argue, have relatively little to offer in terms of meeting basic human needs). The money is there for some things, but relatively little of it is finding its way into agriculture, even in some of the neediest nations. This probably is not a new story in historical terms, but it is a disquieting one as we start to think in terms of future food needs.

B. Institutional Constraints

The total level of funding available for social programs is not the whole story. There also are the questions of how much is available for agriculture and, within that amount, how much is allocated for research.

In terms of development assistance agencies, the problems can be illustrated by USAID (a bilateral agency) and the World Bank (a multilateral institution). Both face problems of maintaining a development focus in the face of a seeming eruption of natural and civil disruptions and crises. Both face a problem of fitting a long-term program such as research into an increasingly tight development budget. Both organizations have relatively few officials or other staff members with agricultural backgrounds or scientific training. And both must give considerable attention to the wishes of their funders or boards, which may lie in other areas.

USAID has been involved in sponsoring agricultural research since the 1960s. Even in days when agriculture was of great importance in the agency, agricultural research had some difficulties in getting established. The situation was described well by Moseman, who was in charge of agricultural research in USAID from 1965 to 1967, in 1970:

> There is still uncertainty...about the feasibility of building and maintaining an effective support base for research and other long-range research activities within an organization so strongly oriented to general assistance, so concerned with highly visible and short-range operational projects, and so subject to frequent reorganizations.

USAID also was, as noted, initially constrained because of Congressional concern about possible competition in export markets. This concern eventually was overcome but re-emerged in the part of farm groups in the mid-1980s, by which time agricultural research had reached its high point in terms of funding and acceptance in the agency. Thereafter, it began a gradual decline as overall funding for agriculture dropped. Many reasons have been mentioned, including decreased development funding in general, increased earmarking by Congress, and a shift in Agency attention to other areas and problems.

The World Bank’s involvement in agricultural research also dates back to the 1960s, and expanded in the 1970s through an extensive program of loans for developing agricultural research programs in developing countries and its grant support for the CGIAR. The loan program has expanded steadily and is limited only by the number of well-developed projects proposed for funding. Grants are a different story: they represent a small proportion of the Bank's portfolio. Grant funding, which comes from Bank earnings, has become tighter, and the competition for grants has expanded. Hence, they have come under increasing scrutiny, especially by those in the Bank who are oriented to loans and who perhaps are less interested in technical aspects of development.

The pattern, as seen at the CGIAR level, is mixed for other multilateral groups. UNDP and the Interamerican Development Bank have reduced their funding. But the European Community has come on strongly.

The developing countries themselves have a large stake in the process, but as noted many of them are facing difficulties in funding their national programs.

7. Looking Ahead

The challenges for public international agricultural research will expand rather than diminish in the future. Some exciting new research tools are coming to hand, but it is uncertain whether they will be harnessed adequately for the needs of the poorer developing countries.

A. Broad Challenges

The principal challenge will come, as always, from population growth. Even though United Nations estimates of future growth rates recently have been scaled back, it still remains that nearly all of the growth will be in developing countries. Compared to 1995, the population in these areas is expected to increase by 51 percent in 2025 and 81 percent by 2050. In some countries, particularly in Africa and the Near East, growth rates will be higher, and total populations will double in 30 years or less. And the rate of growth of population in urban areas, reflecting in part migration from rural areas, will be particularly high. The result is likely to be widening food gaps as measured in terms of meeting per-capita food consumption or minimum nutritional requirements, especially in Sub-Saharan Africa, over the coming decade.

This growth will, of course, call for a corresponding increase in food supply in these regions. The more affluent countries will be able to import food commercially. And, though it has declined in recent years, some food aid doubtless will be available for the more extreme, the near famine, cases of food shortage. But most of the poorer populations will have to rely largely on domestically produced food. Since relatively little suitable land is available to expand production (outside of a few countries in South America), most of the increase, as has been said many times, will have to come from increased yields. Yield expansion, which will not be as simple as many people think, is heavily dependent on the development and delivery of improved technologies and policies; technologies are heavily based on research, and policies may be improved as a result of research.

But more than production expansion is needed; marketing processes also will have to be improved to meet the needs of the expanding urban population. And special efforts will be needed to get adequate food in the hands of the poor and malnourished, wherever they are. All of this will have to be done at a time when environmental issues and natural resources (especially water) will be even more of a constraint than they are now.

B. Research Prospects and Constraints

We recently have seen, and doubtless will continue to see, striking advances in biological

science, especially as it relates to DNA-centered biotechnology, and information technology. Thus, significant opportunities may open up for coping with some of our major scientific and technical problems. A few are beginning to play a notable role in production. The big question is the degree to which it will be possible to transfer the fruits of these efforts to the developing countries, especially the poorer ones.

The private sector, which is responsible for many of the advances, may show some interest in the larger and/or more affluent developing countries, if suitable intellectual property rights (IPR) processes are in place. But it is quite uncertain how much interest they will show toward the basic food crops of the poorest nations, which are largely self-pollinated and which benefit little from IPR regulations even if they exist. [A recent FAO report indicates that in the least developed countries, cereals comprised 62 percent of the daily dietary energy supply, compared to 27 percent in developed countries.]

Public sector research is urgently needed in both developed and developing countries to provide both more basic research and applied research that will not be provided by the private sector. Agriculture is, as Gallup and Sachs of Harvard have noted, part of a larger public goods issue:

> There is no doubt that many of the core issues in tropical health and agriculture are prime examples of international public goods that require a concerted scientific and financial commitment far beyond the means of any individual government. The coordinated agricultural research aid effort is seriously under funded; the situation in tropical public health is even more desperate.

D. Gale Johnson of the University of Chicago, certainly not an alarmist about the world food situation, recently concluded that "If there are to be continuing improvements in the adequacy of food supplies in the developing countries, the world's commitment to agricultural research must not be reduced."

C. Need for Change in Public Attitude

To confront these issues, we urgently need a change in public attitude, by the public at large, their elected representatives, and their government officials, toward development assistance in general and toward agriculture more specifically. In the developed countries, food supply is taken for granted, and in some at the moment the biggest domestic concern is with surpluses. In developing countries, many governments seem to show greater concern for their military establishments than for the welfare of their populations.

In such a setting, public agricultural research tends to be neglected or taken for granted. Many who forecast future production assume that past levels of public investment will continue; we have seen that this is not presently the case. Others assume that the private sector will do the job; we have seen that this is only partially the case, especially for developing countries. Moreover, in some cases where research is making some striking advances, it faces negative reactions on the grounds of food safety or other concerns.

All of this suggests that one of our biggest constraints in achieving food security in future years will be social, the attitude of society. This is one constraint that could, through appropriate educational actions, be alleviated.

8. Concluding Remarks

To invoke an often-used phrase of Charles Dickens in *Tale of Two Cities*, these are the best of times and the worst of times. On one hand, much is now possible in terms of improving global food supplies, but we also face many problems, especially in developing countries. One of the biggest constraints is very limited public resources for meeting this most basic human need.

Malthus recognized part of the problem 200 years ago but, as is well known, underestimated prospects for increasing production. "Malthus' critics, especially the utopians of his time, have argued that man's ingenuity will always keep pace with population growth by finding improved ways to produce food." Probably so for the developed nations, but there is a big question mark in the case of many developing countries and hundreds of millions of the poorer occupants of the earth. It is hard to understand why this situation doesn't elicit more concern. Perhaps part of the answer is to be found in the recent words of an anthropologist: "We are a species that doesn't respond to threats until it's too late."

Duvick recently has cogently summarized the situation as it relates to agricultural research in these words:

> If we hope to implement the advances in food production that are technically possible, we must nurture societal acceptance of agricultural research and muster the political will to support it. Technical innovation will thrive only if it is supported and led forward by the public at large. In the end, society, not science, holds the key to our future food supply.

This aspect of our future may not be beyond our reach, but may be beyond our will.

9. Notes and References

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1. This figure, which is not generally known or published, was derived from data provided by O.

Tampieri of the Statistics Division of FAO, May 1998. In the case of the 28 largest developing countries, the food proportion ranged from a high of 99.7 percent (Ukraine) to a low of 70.4 percent (Uzbekistan). In all but two of the countries, the food proportion was over 90 percent. The comparable figure for the U.S. was 96.0 percent.

2. Based on the *State of Food and Agriculture 1988*, as reported in a November 29, 1998 AFP press account from Rome received on e-mail (the report itself was not available in the U.S. as of this writing).

3. *Ibid.* (drawn from a BBC report on the WWW, December 10, 1998 and also received on e-mail.)

4. See, for example: Seth Mydans, "A Village at Rock Bottom in a Rock Bottom Land," *New York Times*, December 3, 1998; "Child Malnutrition Plagues Cambodia" (World in Brief), *Washington Post*, November 25, 1998, p. A-18; Elizabeth Rosenthal, "In North Korean Hunger, Legacy is Stunted Children," *New York Times*, December 10, 1998, p. A-1; John Pomfret, "Portrait of a Famine," *Washington Post*, February 12, 1999, pp. A1, A30, A31; Karl Vick, "An Anarchic Somalia Lumbers Toward Another Famine," *Washington Post*, December 27, 1998, p. A-23. Iraq shows some of the same characteristics ("Iraq Vows to End Ties to U.N. Food Program," *Washington Post*, December 12, 1998, p. A-19).

5. John M. Goshko, "UNICEF Targets Malnutrition in Yearly Report," *Washington Post*, December 16, 1997.

6. Peter C. Doherty, *Harnessing Science to Solve Global Poverty and Hunger*, World Bank, CGIAR Secretariat, Sir John Crawford Memorial Lecture, October 29, 1998, p. 4.

7. Improved technology also may have other effects, such as improving qualitative aspects (such as flavor) which are prized by consumers and result in higher prices. This appears to have been the case in the Philippines with the third and most recent generation of rice varieties produced by IRRI (*Program Report for 1997*, IRRI, 1998, pp. 90-92).

8. Julian M. Alston and Philip G. Pardey, "International Approaches to Agricultural R & D: The CGIAR," International Food Policy Research Institute (IFPRI), Environment and Production Technology Division (EPTD), February 1999, pp. 33-35, Table 3.1. (Based on J.M. Alston, M.C. Marra, P.G. Pardey, and T.J. Wyatt, "Research Returns Redux: A Meta-Analysis of the Returns to Agriculture R&D," IFPRI, EPTD Discussion Paper No. 38, November 1988.) The highest and lowest 2.5 percent of the rates of return were excluded.

9. The division of agricultural research workers in the public sector in Africa in 1991, for instance, was broken down as follows: government agencies 86.5 percent, universities 10.0 percent, and semi-public entities 3.5 percent (J. Roseboom, P.G. Pardey, and N.M. Beintema, "The Changing Organizational Basis of African Agricultural Research," IFPRI, EPTD Discussion Paper No. 37, November 1998, pp. 23-24, 61).

10. These changes are summarized nicely in a series of articles in a special section on "Evolution of National Agriculture Research Systems" (ed. by Derek Byerlee), *World Development*, June 1998 (Vol. 26, No. 6), pp. 1103-1148.

11. P.G. Pardey, J.M. Alston, and V.H. Smith, "Financing Science for Global Food Security," *IFPRI Report 1997*, 1998, p. 11.

12. I have benefited from discussions with Dr. Josette Lewis of USAID/G/EGAD/AFS in the preparation of this and the next section. She provided several of the citations that follow. Considerable background information on the role of the private sector in agricultural research is provided in: Dina L. Umali, *Public and Private Sector Roles in Agricultural Research; Theory and Experience*, World Bank, Discussion Papers, No. 176, August 1992, 102 pp.; Carl E. Pray and Dina Umali-Deninger, "The Private Sector in Agricultural Research Systems: Will it Fill the Gap?", *World Development*, June 1998 (Vol. 26, No. 6), pp. 1127-1148.

13. During the summer of 1998, two large firms were reported ready to announce plans for significant investments: Monsanto the creation of a $146 million center in St. Louis devoted to basic plant science and sustainable agriculture and Novartis a $250 million plant genomics institute to be built outside San Diego (Jocelyn Kaiser, "Plant Biologists Score Two New Major Facilities," *Science*, Vol. 281, 17 July 1998, p. 317).

14. Robert W. Herdt, "Reflections on Keeping Asia's Food Baskets Full," *American Journal of Agricultural Economics*, 1998 (Vol. 80, No. 5), p. 970.

15. This has been common practice at state colleges of agriculture in the U.S.: "In 1994, nearly 20% of agricultural research at State institutions was funded by private industry, product sales or other private donations, up from 14% in 1978." (Keith Fuglie, *et al*., *Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions*, USDA, Agricultural Economic Report No. 735, May 1996, p.iii).

16. For example, Novartis announced in November 1998 that it will provide at least $25 million to fund research at the Department of Plant and Microbial Biology at the University of California at Berkeley and may provide an equal amount for a new laboratory building. Novartis will not direct the research, saying, "It is our belief that [UCB] knows better than [Novartis] where the best research should be done." ("Novartis Pours Cash into UCB," *Nature Biotechnology*, Vol. 16, December 1998, p. 1298).

17. The Monsanto facility noted above was to be a "public-private consortium." In the UCB case, the "...university was looking for a partner to help fund its research and also wanted to see research impact on society." Zeneca Plant Science (Wilmington, DE) is reported about to "invest $82.5 million into a 10-year wheat genetics research program in an alliance with the John Innes Center and Sainsbury Laboratory in Norwich, U.K." ("News: Collaborations," *Genetic Engineering News*, October 15, 1998, p. 38). An example of an earlier and somewhat different approach is provided by the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) established in 1991 (see Pray and Umali-Denninger, *op. cit.* (see fn. 12), p. 1143, and Clive James, *Agricultural Research Partnerships*, World Bank, CGIAR, Issues in Agriculture 9, December 1996, pp. 31-38.

18. The Ford and Rockefeller foundations established the first international agricultural centers and have remained involved in the international agricultural research arena. Their ranks have grown slightly but not in proportion to needs. The possibilities for further engagement have recently been raised by massive philanthropic grants - not directly to agriculture - by two

affluent businessmen: Ted Turner ($1 billion to the U.N.) and William Gates ($100 million for childhood diseases in developing countries and $4 billion more generally for the William H. Gates Foundation, which focuses on world health and population issues) (Geraldine Fabrikant, "Turner Begins Delivering on U.N. Pledge," *New York Times*, December 7, 1998, p. C8; Lawrence K. Altman, "Gates Giving $100 million to Fight Childhood Disease", New York Times, December 2, 1998; Katie Hafner, "Bill Gates and His Wife Give Away $3.3 Billion," *New York Times*, February 6, 1999, p. A7).

19. Further recent information and perspectives on U.S. engagement are provided in "Report to Congress on Title XII: Famine Prevention and Freedom from Hunger," USAID, December 1998, 54 pp.; and *Proceedings AIARD (Association for International Agriculture and Rural Development) 34th Annual Meeting, June 1998*, Office of Associate Provost for International Affairs, University of Illinois, 114 pp.

20. Details are provided in *Cooperating to Enrich Earth's Capacity: The Agricultural Biotechnology for Sustainable Productivity Project*, Michigan State University, ABSP Project Office, August 1998, 44 pp.

21. See Wanda W. Collins, *US University Collaboration with International Research Centers, 1990-1995*, World Bank, ESDAR, Special Report (1997), 23 pp.

22. *Ibid.*, pp. 3-4. The formal title was "Collaborative Research on Special Constraints for International Agricultural Research Centers."

23. See Roseboom, Pardey, and Beintema, *op. cit.*, pp. 49-53 (see fn. 9).

24. Curt Suplee, "Rescue Effort Ships 'Seeds of Hope' in Bid to Fight Famine in Rwanda," *Washington Post*, December 12, 1994, p. A33. Further detail and analysis are found in Louise Sperling, "Executive Summary and Reflections of Seeds of Hope Socio-Economic Analysis in Rwanda: The Impact of War on Agricultural Production," CIAT, SOH Assessment Document 10, August 1996.

25. "International Effort Launched to Sustainably Restore Food Production in Honduras and Nicaragua Following Hurricane Mitch," World Bank, CGIAR, Future Harvest, news release, January 18, 1999.

26. "A Deluge of Information," *The Economist*, November 28, 1998, p. 86.

27. Dana G. Dalrymple, "The Demand for Agricultural Research: A Colombian Illustration: Comment," *American Journal of Agricultural Economics*, August 1980 (Vol. 62, No. 3), pp. 594-596. While the Cold War played a major role in stimulating overall support for USAID programs, it did not–as far as I could see at the time–have any particular influence on the allocation of funds for agriculture or the operation of these programs (background on this issue is provided in Vernon W. Ruttan, *United States Development Assistance Policy: The Domestic Politics of Foreign Economic Aid*, Johns Hopkins University Press, Baltimore, Md., 1996, pp. 441, 474).

28. Ralph W. Cummings, Jr., "Reverse Technology Flow as a Key to Future World and US

Agriculture," *BioScience*, December 1991 (Vol. 41, No. 11), pp. 775-778.

29. This period is discussed in [Dana G. Dalrymple], "Global Agricultural Research Organization," *Supporting Papers: World Food and Nutrition Study*, National Academy of Sciences, Washington, D.C., Vol. V, Study Team 14 ("Agricultural Research Organization"), 1997, pp. 94-97.

30. Quentin M. West [and Dana G. Dalrymple], "The Developing Countries and U.S. Agricultural Trade," 1970 National Agricultural Outlook Conference, February 16, 1970. Subsequently reprinted in *Foreign Agriculture*, USDA, April 5, 1970, pp. 2-6 and *War on Hunger*, USAID, May 1970, pp. 13-17.

31. Ralph W. Cummings Jr. and Dana G. Dalrymple, "Development Assistance and Exports: the Case of the United States," *Agricultural Economics*, Vol. 3 (1989), pp. 293-307. The case is summarized nicely in P. Pinstrup-Anderson, M. Lundberg, and J.L. Garrett, *Foreign Assistance to Agriculture: A Win-Win Proposition*, IFPRI, Food Policy Report, June 1995; and P. Pinstrup-Anderson and M.J. Cohen, "Aid to Developing Country Agriculture: Investing in Poverty Reduction and New Export Opportunities," IFPRI, 2020 Brief 56, October 1998.

32. Dana G. Dalrymple, *Development and Spread of Semi-Dwarf Varieties of Wheat and Rice in the United States: An International Perspective*, USDA, Agricultural Economic Report 455, June 1980, 150 pp.

33. Dana G. Dalrymple, *Development and Spread of High-Yielding Rice Varieties in Developing Countries*, USAID, 1996, pp. 113-116; *Development and Spread of High-Yielding Wheat Varieties in Developing Countries*, USAID, 1996, pp. 91-97; "Changes in Wheat Varieties and Yields in the United States, 1919-1984," *Agricultural History*, Fall 1998 (Vol. 62, No. 4) pp. 20-36.

34. P.G. Pardey, J.M. Alston, J.E. Christian, S. Fan, *Hidden Harvest: U.S. Benefits from International Research Aid*, IFPRI, Food Policy Report, September 1996. (An expanded version of this work is expected to be published soon as a technical report.)

35. J. von Braun, R.F. Hopkins, D. Puetz, and R. Pandya-Lorch, *AID to Agriculture: Reversing the Decline*, IFPRI, Food Policy Report, October 1993.

36. Pardey, Alston, and Smith, *op. cit*., p. 11 (see fn. 11).

37. Elizabeth Pennisi, "Agriculture Research: 1999 Budget: One Step Forward, Two Back," *Science*, Vol. 282, 16 October 1998, pp. 392-393.

38. "R&D is Big Winner in 1999 Federal Budget," *Issues in Science and Technology*, Winter 1998-99 (Vol. XV, No. 2), pp. 25-27. Further insights are provided in: David Malakoff, "U.S. R&D Budget: Three Spending Bills Bolster Research," *Science*, Vol. 282, 9 October 1998, pp. 209-210, and David Malakoff and Eliot Marshall, "1999 Budget Finale, NIH Wins Big as Congress Lumps Together Eight Bills," *Science*, Vol. 282, 23 October 1998, pp. 598-599. Administration budget proposals for 2000 are reviewed in David Malakoff, "2000 Budget Plays Favorites," *Science*, Vol. 283, 5 February 1999, pp. 778-780.

39. Ruth Leger Sivard, *World Military and Social Expenditures 1996*, World Priorities, Washington, D.C. 1996, pp. 11, 45. Of this total, 73.4 percent was in developed countries (where it represented 2.8 percent of GNP), 19.3 percent in developing nations (3.0 percent), and 7.3 percent in transition states (6.3 percent). The proportions of GNP spent on the military were particularly high in the Near East and North Africa, but also were high in other countries such as Botswana (5.6 percent), Myanmar (4.1percent), and Ethiopia (3.7 percent) (*World Bank Development Indicators 1997*, World Bank, 1997, pp. 182-200).

40. Stephen Lee Myers, "Clinton Proposes a Budget Increase for the Military," *New York Times*, January 2, 1999, p. A1.

41. Tim Weiner, "Big Cash Infusion Aims to Rebuild Anemic C.I.A.," *New York Times*, October 22, 1998. Total appropriations for all intelligence agencies in FY 1998 were $26.7 billion (Vernon Loeb, "CIA Won't Disclose Total Intelligence Appropriation for Fiscal Year," *Washington Post*, December 25, 1998, p. A10).

42. Kenneth J. Cooper, "Grinding Poverty Persists in Newest Nuclear Powers," *The Washington Post*, January 2, 1999, p. A13. In the perhaps extreme case of Cambodia, about 50 percent of the national budget reportedly goes to the military while only 10 percent goes to health care, and 6 percent to education (Mydans, *op. cit.* (see fn. 4)).

43. In "World Briefing," *New York Times*, December 4, 1998.

44. See, for example: Paul Lewis, "World Bank Worried by Pressure for Quick Fix Fiscal Action," *New York Times*, October 5, 1998; Paul Blustein, "World Bank to Expand Crisis Role," *Washington Post*, October 6, 1998, p. C3; Jim Hoagland, "Listen to Little Norway," *Washington Post*, January 24, 1999, p. B7 (refers to U.S. assistance). The conflict side of this issue is outlined in: E. Messer, M.J. Cohen, and J. D'Costa, "Food from Peace: Breaking the Links Between Conflict and Hunger," IFPRI, 2020 Brief 50, June 1998; and I. de Soysa and N.P. Gleditsch, *To Cultivate Peace: Agriculture in a World of Conflict*, International Peace Research Institute, Oslo, Report No. 1, 1999, 98 pp. (sponsored by Future Harvest).

45. A.H. Moseman, *Building Agricultural Research Systems in the Developing Nations*, New York, 1970 (summarized in [Dalrymple], *op. cit.*, 1977 pp. 94-95; see fn. 26 above). Not a lot has changed since this was written, except that the pace of reorganization has slowed. The more general problems at the national level are summarized by J. Thomas Ratchford in "Put Science and Technology Back Into Foreign Policy," *Science*, Vol. 282, 27 November 1998, p. 1650.

46. [Dalrymple], *op. cit.* (see fn. 29 above).

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49. John Bongaarts, "Demographic Consequences of Declining Fertility," *Science*, Vol. 282, 16

October 1998, pp. 419-420; John Bongaarts and Judith Brice, "Population Growth and Policy Options in the Developing World," IFPRI, 2020 Brief 53, October 1998; "Population Tidal Wave," *Washington Post*, January 3, 1997; L. Haddad, M.T. Ruel, and J.L. Garrett, "Growing Urban Poverty and Undernutrition: Implications for Research and Policy," IFPRI, December 15, 1998; and *The State of Food and Agriculture 1998*, *op. cit.* (see fns. 2 & 3).

50. *Food Security Assessment*, USDA, Economic Research Service, GFA-10, December 1998, p. 3.

51. See, for example, Charles C. Mann, "Crop Scientists Seek a New Revolution," *Science*, Vol. 283, 15 January 1999, pp. 310-314.

52. See, for example, Ann Simon Moffat, "Toting Up the Early Harvest of Transgenic Plants", *Science*, Vol. 282, 18 December 1998, pp. 2176-2178.

53. FAO, *op. cit.* (as reported in fn. 3).

54. This point is made more fully in Pray and Umali-Denninger, *op. cit.* (see fn. 12), especially pp. 1143-1144, and in four papers on "Keeping Asia's Food Basket Full" in the *American Journal of Agricultural Economics*, 1998 (Vol. 80, No. 5), pp. 948-972 (see particularly the summary paper by Robert Herdt, pp. 969-972).

55. J.L. Gallup and J.D. Sachs, with A.D. Mellinger, "Geography and Economic Development," Harvard Institute for International Development, December 1998, p. 34. (These conclusions were summarized in the *World Bank Policy and Research Bulletin*, April-June 1998 (Vol. 9, No. 2), p. 3, and in *Der Standard*, Austria, January 1, 1999, p. 35.)

56. D. Gale Johnson, "The Growth of Demand Will Limit Output Growth for Food Over the Next Quarter Century," University of Chicago, Office of Agricultural Economics Research, Paper No. 98: 09, August 22, 1998, p. 23. Also see Charles Mann, "Reseeding the Green Revolution," *Science*, Vol. 277, 27 August 1997, pp. 1038-1042.

57. The general case recently has been summarized in the U.S. context by Hoagland, *op. cit.* (see fn. 44).

58. Malcolm W. Browne, "Will Humans Overwhelm the Earth? The Debate Continues," *New York Times*, December 8, 1998.

59. *Ibid.* (fn. 58).

60. Donald N. Duvick, "Reaping the Fruits of Research," *Forum for Applied Research and Public Policy*, Summer 1998 (Vol. 13, No. 2), p. 81. (Duvick formerly was director of research at Pioneer Hybrid.)

Return to the Table of Contents