Toward a Global Agricultural Research System

Vernon W. Ruttan

Department of Agricultural and Applied Economics, and
Department of Economics, University of Minnesota

Published by the Department of Agricultural Economics,
University of Saskatchewan, Saskatoon

Abstract

A new system of international agricultural research institutes has emerged since the late 1950s. The author reviews the progress of the system, and notes that the system is very important to productivity in smaller countries. There is a continuing need for international support. Areas needing fuller support include agriculture in the tropics and basic scientific knowledge in less developed countries. New facilities should be located in the areas they will do most good, not necessarily just in the developed countries. The system must also become truly global, with better links between national research systems. The author makes a number of specific recommendations for making national research systems more effective. After examining the question of size of system, he details minimum requirements for a national research system and offers some general conclusions. Finally, a formula funding model to make aid more effective is proposed.

Acknowledgements

The College of Agriculture is pleased to recognize the support provided by the Douglas-Coldwell Foundation to establish the Phelps Lectureship at the University of Saskatchewan. Funding for the annual lectureship is provided out of a gift to the Foundation by Mr. W.D. Phelps of North Battleford, Saskatchewan. The objective of the lectureship is to have a noted authority deliver a lecture on a topic related to Social Aspects of Agriculture.

In this inaugural year, the College of Agriculture was fortunate to have Dr. Vernon W. Ruttan, an agricultural economist from the University of Minnesota, present a lecture entitled "Toward a Global Agricultural Research System."

It was a pleasure to work with Dr. T.H. McLeod of the Douglas-Coldwell Foundation to establish this lectureship. We also wish to thank Dr. W.H. Furtan, head of the Department of Agricultural Economics, University of Saskatchewan, for his assistance in selecting a speaker for the first Phelps lecture.

D.A. Rennie
Dean of Agriculture
University of Saskatchewan
Saskatoon, Saskatchewan

Contents

List of Tables

Toward a Global Agricultural Research System

Vernon W. Ruttan

The closing decades of the 20th century mark the end of one of the most remarkable transitions in the history of agriculture. Prior to this century almost all increases in agricultural production depended on expanding the area under cultivation. Major exceptions to this generalization include the introduction of wet rice cultivation in East Asia and the agricultural revolution of the 18th and 19th centuries in Western Europe.

Agricultural production can no longer be expanded by simply adding more land to production. Rather, it will require more intensive cultivation in the areas now being used. Increases in food and fiber production will largely depend on continuous advances in agricultural technology. The development of agricultural research capacity for each commodity of economic significance in each agro-climatic region of the world must be completed over the next several decades.

This paper addresses the task of designing and implementing the global agricultural research system that will need to be in place by, at the very latest, the first decade of the 21st century. Particular attention is given to the special problems of the smaller countries in the emerging global system.

The International Agricultural Research System

What has been accomplished over the last several decades? The architects of the post-war set of global institutions viewed meeting world food needs and reducing poverty in rural areas as essential to their vision of a world community that could assure all people of freedom from want and insecurity. They sought to achieve this vision by the creation of a set of global bureaucracies — the U.N. specialized agencies. The establishment of the U.N. Food and Agriculture Organization was the initial institutional response to this concern (Hambridge).

Not until the late 1950s and early 1960s did a number of factors converge to provide the impetus, on the part of several bilateral and multilateral assistance agencies and national governments, for a major effort to build the research capacity needed to sustain agricultural production in the poor tropical countries. These factors were (a) concern about meeting world food needs, (b) experience in advancing technology in food grain production in the tropics, and (c) a more adequate analysis of the role of agriculture and of advances in agricultural technology.

Organization and Impact

One of the most remarkable advances emerging from the efforts of the last two decades has been the establishment of a new system of international agricultural research institutes (Table 1). The first four institutes were the product of the joint efforts of the Ford and Rockefeller Foundations. The system now operates under the umbrella of the Consultative Group for International Agricultural Research (CGIAR) and is funded by a consortium of private foundations and bilateral and multilateral assistance agencies. An important innovation in the management of the system is that each institute is governed by an independent board of directors and operates as an autonomous institution. This structure, which combines decentralized decision-making in scientific matters with centralized funding and program direction, largely accounts for the productivity of the system. Scientific judgements about programs are decentralized while system design and strategy can be centrally planned.

Table 1: Centers Supported by the Consultative Group for International Agricultural Research, 1984[a]

Acronym, Year Established	Center	Location	Research Programs	Geographic Focus	1984 Budget ($ million U.S.)
IRRI 1960	International Rice Research Institute	Los Banos, Philippines	Rice	Global	
			Rice-based cropping systems	Asia	22.5
CIMMHYT 1966	Centre Internacional de Mejoramiento Maiz y Trigo	Mexico City, Mexico	Maize	Global	
			Bread wheat	Global	
			Durum wheat	Global	
			Barley	Global	
			Triticale	Global	21.0
IITA 1967	International Institute of Tropical Agriculture	Ibadan, Nigeria	Farming systems	Tropical Africa	
			Maize	Tropical Africa	
			Rice	Tropical Africa	
			Sweet potato, yams	Global	
			Cassava, cowpea, lima bean, soybean	Tropical Africa	21.2
CIAT 1968	Centro Internacional de Agricultura Tropical	Cali, Colombia	Cassava	Global	
			Field beans	Global	
			Rice	Latin America	
			Tropical pastures	Latin America	23.1

Table 1, continued

Acronym, Year Established	Center	Location	Research Programs	Geographic Focus	1984 Budget ($ million U.S.)
CIP 1971	Centre Internacional de la Papa	Lima, Peru	Potato	Global	10.9
WARDA 1971	West African Rice Development Association	Monrovia, Liberia	Rice	West Africa	2.9
ICRISAT 1972	International Crops Research Institute for the Semi-Arid Tropics	Hyderabad, India	Chickpea Pigeonpea Pearl millet Sorghum Groundnut Farming systems	Global Global Global Global Global Semi and tropics	22.1
ILRAD 1973	International Laboratory for Research on Animal Diseases	Nairobi, Kenya	Trypanosomiasis Theilenosis	Global Global	9.7
IBPGY 1974	International Board for Plant Genetic Resources	Rome, Italy	Plant genetic resources	Global	3.7
ILCA 1974	International Livestock Center for Africa	Addis Ababa, Ethiopia	Livestock production systems	Tropical Africa	12.7
IFPRI 1975	International Food Policy Research Institute	Washington, D.C., U.S.A.	Food policy	Global	4.2
ICARDA 1976	International Center for Agricultural Research in the Dry Areas	Aleppo, Syria	Farming systems Wheat, barley, triticale, broad lentil, chickpea, forage crops	Dry areas of West Asia and North Africa	20.4
ISNAR 1980	International Service for National Agricultural Research	The Hague, Netherlands	National agricultural research	Global	3.5

*CGIAR-supported core budget, net of capital, at the bottom of the bracket (from 1983 Integrative Report).

Evidence about the productivity of the system is fragmentary and incomplete, but there is little doubt that the rate of return to investment in the system has been high – even compared to the more productive national systems in developed countries (Table 2). As early as the mid-1970s, evidence developed by Robert Evenson and colleagues at the University of the Philippines and the International Rice Research Institute (IRRI) indicated that the supply of rice in all developing countries was approximately 12 percent higher than it would have been if only the varieties available prior to the mid-1960s had been used (Evenson, Flores and Hayami). A recent study by Joseph Nagy suggests that the gains to Pakistan, alone, from the wheat research conducted by CIMMYT (Centre International de Mejoramiento Maiz y Trigo) would have been more than enough to cover the cost of the entire CIMMYT wheat program from its inception to 1980. Another way of making the same point is that Pakistan, on its own, could have afforded to invest in a wheat research program comparable in capacity and cost to the CIMMYT program.

Table 2: Summary of Studies of Agricultural Research Productivity

Study	Country	Commodity	Time Period	Annual Internal Rate of Return (Percent)
Index Number:				
Griliches 1958	U.S.A.	hybrid corn	1940-1955	35-40
Griliches 1958	U.S.A.	hybrid sorghum	1940-1957	20
Peterson 1967	U.S.A.	poultry	1915-1960	21-25
Evenson 1969	South Africa	sugarcane	1945-1962	40
Barletta 1970	Mexico	wheat	1943-1963	90
Barletta 1970	Mexico	maize	1943-1963	35
Ayer 1970	Brazil	cotton	1924-1967	77+
Schmitz & Seckler 1970	U.S.A.	tomato harvester with no compensation to displaced workers	1958-1969	37-46
		... and with compensation for 50% of lost earnings	1958-1969	16-28
Ayer & Schuh 1972	Brazil	cotton	1924-1967	77-110
Hines 1972	Peru	maize	1954-1967	35-40[a] 50-55[b]
Hayami & Akino 1977	Japan	rice	1915-1950	25-27
Hayami & Akino 1977	Japan	rice	1930-1961	73-75
Hertford, Ardila, Rocha & Trujillo 1977	Colombia	rice	1957-1972	60-82
		soybeans	1960-1971	79-96
		wheat	1953-1973	11-12
		cotton	1953-1972	none
Pee 1977	Malaysia	rubber	1932-1973	24
Peterson & Fitzharris 1977	U.S.A.	aggregate	1937-1942	50
			1947-1952	51
			1957-1962	49
			1957-1962	34
Wennergren & Whitaker 1977		sheep	1966-1975	44
	Bolivia	wheat	1966-1975	–48
Pray 1978	Punjab (British India)	research and extension	1906-1956	34-44
	Punjab (Pakistan)	research and extension	1948-1963	23-37
Scobie & Posada 1978	Bolivia	rice	1957-1964	79-96
Pray 1980	Bangladesh	wheat and rice	1961-1977	30-35
Regression Analysis:				
Tang 1963	Japan	aggregate	1880-1938	35
Griliches 1964	U.S.A.	aggregate	1949-1959	35-40
Latimer 1964	U.S.A.	aggregate	1949-1959	not significant
Peterson 1967	U.S.A.	poultry	1915-1960	21
Evenson 1968	U.S.A.	aggregate	1949-1959	47
Evenson 1969	South Africa	sugarcane	1945-1958	40

Table 2, continued

Study	Country	Commodity	Time Period	Annual Internal Rate of Return (Percent)
Barletta 1970	Mexico	crops	1943-1963	45-93
Duncan 1972	Australia	pasture improvement	1948-1963	58-68
Evenson & Jha 1973	India	aggregate	1953-1948	40
Cline 1975 (revised by Knutson & Tweeten 1979)	U.S.A.	aggregate	1939-1948	41-50[c]
		research and extension	1949-1958	39-47[c]
		research and extension	1959-1968	32-39[c]
		research and extension	1969-1972	28-35[c]
Bredahl & Peterson 1976	U.S.A.	cash grains	1969	36[d]
		poultry	1969	37[d]
		dairy	1969	43[d]
		livestock	1969	47[d]
Kahlon, Bal, Saxena & Jha 1977	India	aggregate	1960-1961	63
Evenson & Flores 1978	Asia — national	rice	1950-1965	32-39
		rice	1966-1975	73-78
	Asia — international	rice	1966-1975	74-102
Flores, Evenson & Hayami 1978	Tropics	rice	1966-1975	46-71
	Philippines	rice	1966-1975	75
Nagy & Furtan 1978	Canada	rapeseed	1960-1975	95-110
Davis 1979	U.S.A.	aggregate	1949-1959	66-100
		aggregate	1964-1974	37
Evenson 1979	U.S.A.	aggregate	1868-1926	65
	U.S.A.	technology-oriented	1927-1950	95
	U.S.A.	science-oriented	1927-1950	110
	U.S.A.	science-oriented	1948-1971	45
	Southern U.S.A.	technology-oriented	1948-1971	130
	Northern U.S.A.	technology-oriented	1948-1971	93
	Western U.S.A.	technology-oriented	1948-1971	95
	U.S.A.	farm management research and agricultural extension	1948-1971	110

[a] Returns to maize research only.

[b] Returns to maize research plus cultivation "package".

[c] Lower estimate for 13-year, and higher for 16-year time lag between beginning and end of output impact.

[d] Lagged marginal product of 1969 research on output discounted for an estimated mean lag of five years for cash grains, six years for poultry and dairy, and seven years for livestock.

Source: Evenson, Waggoner and Ruttan.

Note: The studies are listed in the Appendix. Works that summarize the studies include:

Thomas M. Arndt, Dana G. Dalrymple, and Vernon W. Ruttan (eds.), *Resource Allocation and Productivity in National and International Agricultural Research* (Minneapolis: University of Minnesota Press, 1977), pp. 6, 7.

James K. Boyce and Robert E. Evenson, *Agricultural Research and Extension Systems* (New York: Agricultural Development Council, 1975), p. 104.

Robert Evenson, Paul E. Waggoner, and Vernon W. Ruttan, "Economic Benefits from Research: An Example from Agriculture," *Science*, no. 205 (14 September 1979), pp. 1101-1107.

Robert J.R. Sim and Richard Gardner, *A Review of Research and Extension Evaluation in Agriculture* (Moscow, Idaho: University of Idaho, Department of Agricultural Economics Research Series no. 214, May 1978), pp. 41, 42.

Support for Small Country Systems

The international system is particularly important for enhancing and sustaining the productivity of the smaller national agricultural research systems. In the late 1970s I visited the rice research station at Mopti in Mali. The scientific staff at the station consisted of four young men — a rice breeder, an entomologist, a plant pathologist and an agronomist who had recently returned from completion of Master's level (or equivalent) training abroad. They had access, through the West African Rice Development Authority (WARDA), to the IRRI germ plasm collections. Their professional isolation was relieved and their productivity enhanced through participation in WARDA and IRRI workshops and seminars. A decade earlier they would have had little access to either the genetic resources or the intellectual contact that enabled them, in the late 1970s, to initiate a modest yet productive research program.

As a second example, at the 1984 Agricultural Research Policy seminar held at the University of Minnesota, a research director from one of the smaller Latin American countries commented to the effect that:

> It is very well for those from Mexico or Brazil to talk about the strength of your national systems and how little you gain from the international centers. But without the international centers we would not get anything from you. The international centers are there working with us to make sure we have access to the available technology. The primary factor that limits what we get through the centers is our own capacity to use it.

A Continuing Need for International Support

When the system of international centers was being established by the Ford and Rockefeller Foundations in the early and mid-1960s there was a general perception that over a period of several decades the foundations would withdraw and transfer the management and support of the institutes to the host countries. The two foundations have now withdrawn from anything more than token support of the system. But responsibility for overseeing and support has been assumed, as noted earlier, by the CGIAR and its member institutions. Yet one still hears comments from staff members of both the developed country (DC) donors and the less-developed country (LDC) national research systems that at some time in the future the responsibility for the system can be transferred to the LDCs or that the major units of the system (excepting the International Board for Plant Genetics Resources) will eventually be phased out.

Such discussion is unrealistic. The system should be viewed as a permanent component of the global agricultural support system. This does not mean that every unit in the present system should be regarded as permanent. It is not difficult to visualize circumstances that should lead to the de-emphasis of some programs and the initiation of new programs. But the international system should be regarded as permanent. And the funding for the system should become part of a permanent commitment of the more developed countries to the agricultural development of the poorer and smaller countries in the system. In this respect there is a similiarity between the national funding of a system of regional research centers, in larger countries such as Brazil, India and the United States, even though the individual states also support experiment stations.

An Incomplete System

Though a permanent commitment to the support of the international systems is necessary, the system remains incomplete. This is not an argument for any significant expansion of the system of international commodity research institutes. But the managing and overseeing of a number of international agricultural research centers that have grown up outside of the CGIAR system (Table 3) should be rationalized. Also, greater capacity to conduct research on some of the difficult resource problems that continue to inhibit the development of agriculture in tropical environments is needed, and the lack of basic scientific knowledge seriously constrains the development of viable technologies in some areas.

Table 3: Some International Agricultural Research Activities Outside the CGIAR[a]

Center	Primary Focus	Location	Year of Initial Operation	Budget US$m	Budget (Year)	No. of Senior Staff	Programs
ICIPE	insect physiology and ecology	Nairobi, Kenya	1970	4.77	(1982)	46	crop borers livestock ticks tsetse fly plant resistance medical vectors insect pathology pest management
AVRDC	tropical vegetables	Shanhua, Taiwan, China	1972	3.60	(1983)	32	tomato Chinese cabbage sweet potato soybean mungbean
ICLARM	living aquatic resources	Manila, Philippines	1973	1.70	(1983)	14	aquaculture traditional fisheries resources development and management information services
INTSOY	soybeans	Urbana, Illinois, U.S.A.	1973	0.95	(1983)	8	soybeans

Table 3, continued

Center	Primary Focus	Location	Year of Initial Operation	Budget US$m	Budget (Year)	No. of Senior Staff	Programs
IFDC	fertilizer	Muscle Shoals, Alabama, U.S.A.	1974	6.70	(1982)	60	nitrogen research nutrient interaction phosphate research sulfur research potassium research economics research national programs technical assistance training
ICRAF	agro-forestry	Nairobi, Kenya	1978	2.20	(1983)	18	agro-forestry systems agro-forestry technology information training colaborative research
IIMI	irrigation management	Kandy, Sri Lanka	1984	5.00	(when operational)	10-12 in HQ, 3-4 /unit	collaborative research training information dissemination
IBSRAM	soils	not fixed	1985	4.54	(when operational)	5-10	headquarters soil management networks
INIBAP	banana and plaintains improvement	not fixed	1985	1.75	(initially)	small	headquarters regional networks

*Activities currently using CGIAR meetings or in some other way related to CGIAR activities in 1984 (totalling about $30 million).

The establishment of an International Fertilizer Development Center at Muscle Shoals, Alabama, in 1974 was an initial step in the devleopment of an international capacity to research resource development and management problems. The recent decision by a group of donors to estalbish an International Irrigation Management Institute (IIMI) in Sri Lanka is a second significant initiative. There is widespread discussion in forestry circles of the need for greater capacity in the tropics for research on the development, management and utilization of fast-growing trees to sustain the demand for biomass for fuel and other uses.

International support is beginning to be applied to some of the problems where lack of basic knowledge constrains technological development. Within the CGIAR system the International Laboratory for Research on Animal Diseases (ILRAD) has been forced to direct much of its research to basic investigations. The International Centre for Insect Physiology and Ecology (ICIPE), initially established in 1970, has gradually evolved into an institution with very substantial research capacity. The United Nations Industrial Development Organization (UNIDO) has sponsored exploratory studies that are leading to the establishment of an International Centre for Genetic Engineering and Bio-

Technology (ICGER). It is doubtful, however, that the ICGER will devote adequate attention to the work in molecular biology that will be most relevant for animal and plant protection in developing countries. There also seems to be a very strong need for capacity to conduct research to overcome the lack of knowledge about problems of fertility maintenance and enhancement of tropical soils. In many parts of Africa, lack of knowledge about soil fertility limits the ability to design viable short-rotation systems to replace the more extensive slash-and-burn or other long-rotation systems now in use. Finally, there are serious deficiencies in the knowledge needed to develop economically viable technologies for the control of parasitic diseases that inhibit the development of more intensive systems of agricultural production. In many cases, the relationship between disease and development appears to be symbiotic: intensification of agricultural production enhances the environment for parasitic disease, while parasitic disease reduces the capacity of rural people to pursue more intensive systems of cultivation.

It is not too difficult to generate agreement, at least in principle, for greater international support of research into problems of resource development and management. But there is considerable skepticism about the need for international support for a series of basic research institutes in the tropics. The argument is frequently made that the basic research can be done in developed countries' institutes, particularly in countries such as France, the United Kingdom and the Netherlands, which have a tradition of tropical research and are now seeing that capacity erode as support adjusts to the disappearance of colonial responsibilities and to budget exigencies. However, the intellectual commitment to the solution of even scientific problems is enhanced when the scientists are located in the environment in which the problem exists. Basic research capacity in the tropics will also facilitate more effective dialogue with the basic research community in the developed countries.

Considerable thought must also be given to the appropriate governing of the emerging system of natural resource and basic science research centers. The present CGIAR system is already approaching the levels of its financial and managerial capacity. Yet it would be a serious mistake if new natural resource and basic science institutes continued to emerge on an *ad hoc* basis. One of the great strengths of the present system is that the CGIAR, in its role of planner and overseer, welds the set of autonomous institutes into an international research system. It may be necessary to establish new umbrella bodies, such as a Consultative Group for Natural Resources Research, to govern the new institutes with a natural resource base. And it will certainly be necessary to establish a separate governing system for any new system of basic research institutes — a Consultative Group of Biological Sciences for Tropical Agriculture. As new internationally supported basic research units are established in the tropics, more attention should be given to the training role, particularly advanced training at the Ph.D. and post-doctoral levels, than was the case when the present international commodity institutes were established.

A Global System

Finally, an effort should be made to assure that the international system becomes a truly global system. The new international system has been effective in building communication among LDC national research systems. The ties between international centers and developed countries' institutions, are, however, generally by way of the bilateral development assistance agencies. Direct links with the national research systems of the developed countries remain minimal. The links between the national research systems of the developed countries are even more rudimentary. For example, it appears that there is no institutional capacity to rationalize or co-ordinate agricultural research among EEC member countries. There is a modest program of information exchange among OECD countries but the activities appear to be more ceremonial than substantive. And there are no effective links between either of these international research systems with the agricultural research systems of the socialist countries.

National Research Systems

The last several decades have also witnessed a remarkable expansion in agricultural research capacity in a number of important developing countries. The number of agricultural scientists in the developing countries of Latin America, Africa and Asia rose from approximately 14,000 in 1959 to 63,000 in 1980 (Table 4).

When one examines the individual countries, however, it is clear that most of this growth has occurred in relatively few countries, such as Brazil, the Philippines, India, China and Nigeria. In 1980 there were only slightly more agricultural research scientists in all of Latin America and Africa combined than in the U.S. federal-state system — and fewer than in the Japanese national-prefectural system. Even in those countries that have made substantial progress, the ratio of research expenditures to the value of production remains low — and it remains lowest for those commodities produced and/or consumed primarily by the poorest farmers and consumers.

During the last several years I have been involved in a series of studies of agricultural research systems in Asia (Ruttan, 1981). The concerns about the development of national agricultural research systems that have emerged out of my research and experience have been reinforced by the series of very useful reviews conducted by the World Bank (1983), the U.S. Agency for International Development (1983) and the UNDP-FAO (1984). Some of these concerns are as follow.

1. Investment in research facilities seems excessive relative to development of scientific staff. There are too many facilities with programs. Many of the premature facility developments are the direct result of the multilateral and bilateral assistance agency programs that find it easier to invest in facility development than in human development or program support. Premature investment in facilities represents a burden on the research system rather than a source of productivity.

2. The excessive administrative burden stifles both routine investigations and research entrepreneurship. A major challenge to any national research system is how to make the personal and professional objectives of individual researchers, research teams and research managers consistent with the social objectives of the research system. In many respects the individual scientist can appropriately be viewed as an independent contractor who makes his or her services available in return for professional and economic incentives. Bureaucratic efforts to achieve consistency between the objectives of the individual and system objectives, or simply fiscal responsibility, is often carried to the point where it becomes an excessive burden on research productivity.

3. Decisions about the location of major research facilities, often made with the advice of assistance agency consultants, have frequently failed to give adequate weight to the factors that contribute to a productive research location. These factors include (a) location in a community that includes related educational and professional infrastructure; (b) location in an agro-climatic environment that is representative of an important part of the area in which the particular commodity is grown or which is representative of a major resource (soil, water) problem area; (c) selection of a site with appropriate resource (soil, water) and infrastructure (electricity, transport, amenity) characteristics.

4. Research budgets do not correspond to the economic importance of major commodities or commodity groupings. If new knowledge and new technology were equally easy (or difficult) to come by in each commodity area, a good rule of thumb would be to allocate research resources roughly in proportion to the value (or value added) of commodity output or resource input. It is easy to think of good reasons for departure from such a rule. In a small research system, critical mass (i.e., scale economies) implies the desirability of focusing resources on areas that account for a large share of output (e.g., rice) or on a commodity where very large gains can be made in a short time (e.g., lowland irrigated rice in the 1960s). But extreme lack of congruence often suggests that little careful thought has been given to research resource allocation or that particular interest groups have biased research allocation for their own benefit.

5. There is a lack of information and analysis going into establishment of research priorities and thrusts. In the research planning staffs that have successfully struggled with the research resource allocations problem, it has become increasingly obvious that effective research planning requires close collaboration between natural and social scientists and among agronomists, engineers and planners. This is because any research resource allocation system,

Table 4: Trends in Numbers of Research Scientists and Extension Workers, 1959-80

Region/Subregion	Research Scientists[a]			Extension Workers			Ratio of Extension Workers to Research Scientists		
	1959	1970[b]	1980	1959	1970[b]	1980[c]	1959	1970	1980
Western Europe	6,251	12,547	19,540	15,988	24,388	27,881	2.56	1.94	1.43
Northern Europe	1,818	4,409	8,027	4,793	5,638	6,241	2.64	1.23	0.78
Central Europe	2,888	5,721	8,827	7,865	13,046	14,421	2.72	2.28	1.63
Southern Europe	1,545	2,417	2,686	3,330	5,704	7,219	2.16	2.36	2.69
Eastern Europe and USSR[d]	17,701	43,709	51,614	29,000	43,000	55,000	1.64	0.98	1.07
Eastern Europe	5,701	16,009	20,220	9,340	15,749	21,546	1.64	0.98	1.07
USSR	12,000	27,700	31,394	19,660	27,251	33,454	1.64	0.98	1.07
North America and Oceania	8,449	11,688	13,607	13,580	15,113	14,966	1.61	1.29	1.10
North America	6,690	8,575	10,305	11,500	12,550	12,235	1.72	1.46	1.19
Oceania	1,759	3,113	3,302	2,080	2,563	2,731	1.18	0.82	0.83
Latin America	1,425	4,880	8,534	3,353	10,782	22,835	2.35	2.21	2.68
Temperate South America	364	1,022	1,527	205	1,056	1,292	0.56	1.03	0.85
Tropical South America	570	2,698	4,840	2,369	7,591	16,038	4.16	2.81	3.32
Caribbean and Central America	491	1,160	2,167	779	2,135	5,505	1.59	1.84	2.54

Table 4, continued

Region/Subregion	Research Scientists[a] 1959	Research Scientists[a] 1970[b]	Research Scientists[a] 1980	Extension Workers 1959	Extension Workers 1970[b]	Extension Workers 1980[c]	Ratio of Extension Workers to Research Scientists 1959	Ratio 1970	Ratio 1980
Africa[d]	1,919	3,849	8,088	28,700	58,700	79,875	14.96	15.25	9.88
North Africa	590	1,122	2,340	7,500	14,750	22,453	12.71	13.15	9.60
West Africa	412	952	2,466	9,000	22,000	29,478	21.80	23.11	11.95
East Africa	221	684	1,632	9,000	18,750	24,211	40.72	27.41	14.84
South Africa	696	1,091	1,650	3,200	3,200	3,733	4.60	2.93	2.26
Asia[d]	11,418	31,837	46,656	86,900	142,500	148,780	8.55[e]	7.28[e]	5.06[e]
West Asia	457	1,606	2,329	7,000	18,800	16,535	15.31	11.71	7.10
South Asia	1,433	2,569	5,691	57,000	74,000	80,958	39.80	28.80	14.23
Southeast Asia	441	1,692	4,102	9,500	30,500	33,987	21.54	18.03	8.29
East Asia	7,837	13,720	17,262	13,400	19,200	17,300	1.71	1.40	1.00
China	1,250	12,250	17,272	—	—	—	—	—	—
World Total	47,163	108,510	148,039	177,521	294,483	349,337	3.98[e]	3.06[e]	2.67[e]

[a]Estimates of number of research scientists include only workers with advanced degress. An attempt has been to include only research workers engaged in production-related agricultural research. Research on post-harvest technology is, for example, not included in these estimates.

[b]1970 data are an average of 1968 and 1971.

[c]1974 data are used when more recent data are not available. In other cases, the 1980 data are averages for 1974-1980.

[d]Data for Extension Workers in Eastern Europe, USSR, Africa, and Asia are estimated.

[e]Excludes China, for which data on extension workers were not reported.

Source: M. Ann Judd, James K. Boyce, and Robert E. Evenson, "Investing in Agricultural Supply." Presented at Workshop on Agricultural Growth, Economic Growth Center, Yale University, June 20-21, 1983.

regardless of how intuitive or formal the methodology employed, cannot avoid making judgments about two major questions.

First, what are the possibilities of advancing knowledge or technology if resources are allocated to a particular commodity problem or discipline? This can only be answered with any degree of authority by scientists who are on the leading edge of the research discipline or of the problem being considered. The intuitive judgments of research administrators and planners are rarely adequate to answer such questions.

Second, what will be the value to society of the new knowledge or technology if the research is successful? The intuitive insights of research scientists and administrators are no more reliable in answering questions of value than are the intuitive insights of research planners in evaluating scientific or technical potential. Many of the arguments about research resource allocation flounder on the failure of the participants to clearly recognize the distinction between these two questions and the differences in expertise and judgment that must be brought to bear in responding to them (Ruttan, 1982, pp. 262-64).

6. Some national systems apparently presume that it is possible to do agricultural science without scientists. In too many national research systems, commodity program leaders often have neither the training nor capacity to direct either scientific research or technological development. Salary structures and non-economic incentives are frequently so unattractive, relative to other national and international alternatives, that potential leadership is eroded, research programs become routine, and returns to research investment are low.

7. Cycles of development and erosion of capacity have characterized a number of national agricultural research systems. There is a disturbing tendency among the systems that have had the longest history of development with substantial external assistance. Periods of rapid development have often been followed by the erosion or collapse of research capacity when external support has declined. Martin Pineiro, Eduardo Trigo and their colleagues have documented this pattern most thoroughly in a number of Latin American countries such as Argentina, Peru, and Columbia (Ardila, Trigo and Pineiro, 1980; Pineiro and Trigo, 1983). But those of us who have worked in other parts of the world can each pick examples familiar to us.

This does not suggest that the perspectives and concerns expressed about agricultural research in LDCs are the exclusive problems of new and growing research systems. Don Hadwiger has provided evidence that, in the United States, the "pork barrel" approach to the location of agricultural research facilities resulted in 44 percent of all USDA research facility construction between 1958 and 1977 occurring in states represented by members of the Subcommittee on Agriculture of the Senate Appropriations Committee. He noted that this practice has forced "the federal Agricultural Research Service to operate a 'traveling circus' opening up new locations in current Senate constitutencies, while closing some locations in states whose Senators are no longer members of the subcommittee."

Small Country Agricultural Research Systems

The concerns outlined above impinge most severely on the development and management of agricultural research systems in small countries. There is a remarkable paucity of data and analysis on the relationship between scale (or size) and productivity in agricultural research. And what evidence there is, even in the way of casual observation, often lacks precision as to whether the size-output relationship being referred to is with respect to the size of the individual research unit (team, laboratory, department), the individual research institution (center, institute, faculty), or the national or international research system. The view that small is better has often been advanced with considerable heat but with relatively little precision in concept or definition and with even less empirical evidence. The issues discussed in this section represent an important opportunity for research to bring better theory, method and data to bear in order to advance understanding.

Size and Productivity in Research

The meager knowledge of the issue suggests that the optimum scale of research is affected by factors both external and internal to the research process. The optimum level of resources devoted to a commodity research program, as demonstrated rigorously by Binswanger, is positively related to the area planted to a commodity in a particular agro-climatic region. Determining the optimum scale of a research unit or progam involves, therefore, balancing the increasing returns associated with the area devoted to the commodity (or problem) against the possible internal diseconomies of scale of the research process or system.

The available data suggest that industrial research and development productivity, measured in terms of patents per engineering or scientific worker, is lower in the large laboratories of the largest firms than in the smaller firms in the same industry (Schmookler, Kamien and Schwartz). Pound and Waggoner found similar evidence for agricultural research. A number of case studies suggest very high rates of return to individual public, philanthropic, and private research units, often with fewer than 20 scientific or technical staff members per unit (Evenson, 1977; Sehgal, 1977). Many of the smaller "freestanding" agricultural research units are, however, engaged primarily in screening, adapting and transferring technology, which depends only minimally on in-house capacity in such supporting areas as physiology, pathology, chemistry, and even modern genetics.

Evenson also noted that, during the early stages in the development of national research systems, experiment stations tend to be widely diffused, to utilize primarily technical and engineering skills, and to be characterized by a strong commodity orientation. He also pointed to a trend toward hierarchical organization and consolidation into a smaller number of larger units at later stages in the development of agricultural research systems. These centralizing trends are apparently motivated in part by the economies resulting from research activities in the basic and supporting sciences and by the economical use of the laboratory, field, communications, and logistical facilities.

The urge for consolidation can, however, easily be overdone. In the United States, for example, there is now rather strong evidence supporting the value of decentralization even within individual states. For a given level of expenditures, a state system that includes a strong network of branch stations gets more for its research dollar than a more concentrated state system. What decentralization gives up in terms of lower costs seems to be more than compensated for by the relevance of the research and the more rapid diffusion of results. There are, of course, limits to the gains from decentralization. The gains vary among commodities and are influenced by the diversity of agro-climatic conditions and the area devoted to the crop in each agro-climatic region.

A Minimum National System

One of the most difficult issues related to size and productivity in agricultural research is the problem smaller countries face in developing their agricultural research systems. Most of the smaller countries — those in the 4- to 10-million population range — do have the resources, or access to donors' resources, that would permit them to develop, over a 10- or 20-year period, an agricultural research and training capacity capable of staffing the nation's public- and private-sector agricultural research, education, planning and service institutions. The fifty or so smallest low-income countries must, however, think of research systems that will often be little larger than a strong branch station in a country such as the Netherlands or Denmark or in a state such as Texas or Minnesota.

But how can the government of a small country decide on the appropriate size and organization of its national agricultural research system? For countries like Sierra Leone or Nepal, even the financial and professional agricultural research resources of a small American state or a Japanese prefecture are probably at least a generation in the future. The time required to achieve viable research systems for many of the smaller national systems must realistically be calculated in terms of a generation rather than the 5- or 10-year project cycles used by most development assistance agencies.

One major focus of the research effort in these smaller research systems must be the direct support of agricultural production and rural development programs. This means focusing on applied fields such as agronomy, plant breeding, animal production, crop production, farming systems and agricultural planning and policy. Trigo and Pineiro estimate that a minimum research module for one product requires a team consisting of four researchers trained at the M.S. and Ph.D. levels, complemented by eight specialists with graduate level training, plus support personnel. They estimate total costs of such a program in the range of 25,000 1984 U.S. dollars (Table 5). For a small country with six to

Table 5: Estimated Cost of a Minimum Research Module for One Product (thousands of 1984 U.S. dollars)

I. Direct Research costs (60% of total budget)			US$306
A. Personnel		245	
1. 4 chief researchers, M.S. or Ph.D. 3 person/years in plant breeding, agronomy and pest and disease control and 1 person/year equivalent in socioeconomics and other specializations according to requirements (soils, physiology, etc.). Total cost per person/year US$30,000	120		
2. 8 specialists, university graduates. Total cost per person/year US$12,500	100		
3. Training	25		
Calculated on the basis of 2x1 rate of retention; total rotation every 15 years; cost of US$100.000 per Ph.D. (M.S. 60%) Total annual cost for a permanent team of 3 Ph.D. and 1 M.S. (approximately).			
B. Services and materials Calculated as 12.5% of direct costs.		38	
C. Equipment Calculated as 7.5% of direct costs.		23	
II. General Costs and Administration (40% of total budget)			204
Includes direction, support and services (administration, laboratories, library, communications, field, etc.).			
A. Personnel Calculated as 60% of general and administrative costs.		122	
B. Services and materials 25% of general and administrative costs.		51	
C. Investments and equipment 15% of general and administrative costs.		31	
Total Budget			510

Percentage summary by broad budgetary items (approximate)	
A. Personnel	72.5%
B. Services and materials	17.5%
C. Equipment	10.0%

Notes: Estimates were made using the budgetary structure of the international agricultural research centers as a guideline in determining the percentage of each item of expenditure. The figure of $30,000 (U.S.) was used as an average of the case for the different countries of the region. The sum includes salaries plus benefits. A variation of $1,000 above or below this average figure implies an increase or decrease of $4,250 in the total budget.

Source: Eduardo Trigo and Martin E. Pineiro, p. 85.

ten major commodities and several important agro-climatic regions this implies a research budget of 5.0 to 8.0 million U.S. dollars. When this effort is complemented by the non-commodity-oriented research in areas such as soil and water, pest management, cropping systems and socio-economic aspects of agricultural production marketing and policy, the implications run into the $12 to $15 million range.

The viability of even a small nation's agricultural production also requires capacity for higher education, in agriculture, at least through the Master's level, to support national programs of technology in transfer, rural development, and regulatory and service activities. When these activities are aggregated it is not difficult to arrive at a minimum level of professional capacity, with training at the M.S. and Ph.D. levels, of around 250 personnel and with budget support somewhere in the $20-$30 million range for even the smaller (but not the smallest) countries. For the very smallest countries even this investment is not feasible in the foreseeable future. For one of the more serious attempts at a solution to the smallest country problems, refer to the recent paper by Wilson of the University of West Indies.

Interdependent Systems

The idea of reducing or eliminating technological dependency generates strong emotional appeal. Yet even larger countries with advanced agricultural research systems — the United States, the Soviet Union, Japan, India, and Brazil, for example — are not able to be self-sufficient in agricultural science and technology. An effective national agricultural research system must have the capacity to borrow both knowledge and materials from the entire world. The problem of how to link effectively with an increasingly integrated and interdependent global agricultural research system is difficult for the state and provincial research units in the larger national systems. It is even more difficult for the national agricultural research systems in the smaller countries.

One approach to this problem has been to attempt to establish co-operative regional research programs — for example, the West African Rice Development Association (WARDA) and the international crop research networks that are linked to the international agricultural research institutes. Other regional institutions not directly linked to the international (CGIAR) system include the Centro Agronŏmico Tropical de Investigacion y Ensenanza (CATIE), the Caribbean Agricultural Research and Development Institute (CARDI), and the Southeast Asian Fisheries Development Center (SEAFDEC). It is hard, however to find many outstanding success stories among these efforts. Program activities and co-operative efforts often appear stronger in the glossy pamphlets issued by the organizations than they do in practice (Venezian, 1984). It seems that such regional programs can succeed only with the commitment of long-term external support and with the participation of the external donors in the governance of such centers. Some of the most effective collaborative regional efforts have been organized around the research programs of the international research centers (Plucknett and Smith, 1984).

The international crop research networks, centered around the international institutes, have not, however, been without problems. When the institutes have had confident and effective leadership, they have often played an exceedingly useful role in creating opportunities for productive professional interaction and collaboration. But the institute research networks tend to be selective. At times they have found it hard to bend institute priorities to meet national priorities. Collaborative efforts tend to involve the strongest institutions and the leading scientists rather than those who have the greatest need.

A richer institutional infrastructure is needed to strengthen and sustain the capacity of the smaller national agricultural research systems. In spite of ideological considerations, many small countries have found it advantageous to encourage the transfer and adaptation of technology by the private-sector genetic supply industry or by the multinational firms engaged in commodity production, processing, and trade. Firms engaged in the production of crops grown under plantation systems, and independent growers producing under contact arrangements with processors, have at times provided their own research and development facilities. In other cases, associations of producers have been willing to tax themselves to support commodity research stations. Such arrangements have often been associated with discredited systems of colonial government. A strong case can be made for re-examining and strengthening the incentives for private sector research, development and technology dissemination.

The perspectives outlined in this section are highly tentative. Although they are drawn from considerable experience, they should be treated as hypotheses to be tested by further research rather than as conclusions. Institutions such as the IADS, ISNAR and CTA should devote a reasonable amount of analytical effort to attempts to understand the problem of developing and sustaining effective agricultural research in the smaller national research systems.

Some Generalizations

In spite of the limited knowledge that is available, there are a few generalizations about smaller agricultural research systems that can hardly be avoided.

1. The research investment per acre or per hectare will have to be higher in a small system than in a larger system in order to achieve an equal level of effectiveness. This is because the cost of developing, for example, a new millet variety that will be grown on a million acres is not likely to be substantially greater than one that will be grown on half a million acres.

2. The cost of developing productive farming systems for a small country with great agro-climatic variations will be greater than for a small country that is more homogeneous. For example, the cost per hectare of developing an effective agricultural research system for Sri Lanka is likely to be much larger than developing one for Uruguay. The issue of guns versus butter in national budgets is also likely to cut more sharply in a small country than in a large country.

3. A small country cannot avoid being dependent on others — on the international agricultural research system, on the research systems of large countries in the same region, on multi-national firms — for much of its agricultural technology. Furthermore, a small nation with a strong research program but a limited agricultural or industrial base cannot capture as high a proportion of the benefits from its investment in basic research as can a large nation with a diversified economic base. Much of the benefit will spill over to other countries. If it has a weak agricultural research system, it will lack the knowledge needed to capture the benefits of research in other countries or to choose a technological path consistent with its own resource and cultural endowments. Even a strong agricultural research system cannot assure autonomy. But small countries do need to develop sufficient agricultural science capacity to enable them to draw selectively on an interdependent global agricultural research system. They need to be able to choose what is useful when borrowing from other national systems and from the international system.

Toward a Reform of Agricultural Research Support

What can be done to replace the deficiencies that characterize assistance for the support of agricultural research, extension and rural development programs in poor countries? A solution to the problems of "aid effectiveness" in support of research is particularly important at this time. The next decade will likely see a decline in the real flow of aid resources and increasing competition among the several claimants on aid resources.

The basic thrust of the reform that is needed is to move away from primary reliance on narrow project approaches. In supporting agricultural research the project system should be largely replaced by a "formula funding" or "revenue sharing" approach (Ruttan, 1984). Among the many criticisms of the project approach followed by the major bilateral and multilateral development assistance agencies, the most frequently heard is that the assistance agencies exert undue influence on the content of the national development programs. This criticism is partly correct. It is not too difficult to identify cases where close patron-client bonds have been established between particular officers in the aid agencies and the leadership of favored national program agencies. Such relationships have often appeared to give particular national programs a degree of stability and continuity that would be difficult to achieve in the unstable political environments that characterize many developing countries.

Cycles of development and erosion are inherent in the traditional project approach because external assistance provides an alternative to the development of internal political support. National research system directors have frequently found that the generation of external support requires less intensive entrepreneurial effort than the cultivation of domestic political support. Domestic budget support required by donors is often achieved by creative manipulation of budget categories rather than by increments in real program support — particularly when donor representatives are under pressure from assistance agency management to "move resources." Most existing project systems thus have built-in incentives for national research system leaders to direct entrepreneurial effort toward the donor community rather than toward the domestic political system.

Any effective alternative should reverse the perverse incentives that characterize existing development assistance instruments. The system should be reformed to provide national research system directors with incentives to redirect their entrepreneurial efforts toward building domestic political and economic support for agricultural development.

It is increasingly apparent that the long-term viability of agricultural research systems depends on the emergence of organized producer groups who are effective in bringing their interests to bear on legislative and executive budgetary processes. The support of finance and planning ministries for agricultural research is undependable. Their support tends to fluctuate with the perceived severity of food crises and foreign exchange demands.

A Formula Funding Model

What alternatives to the existing system does this paper suggest? It should not be interpreted as completely negative about traditional development assistance instruments. Project aid is often quite appropriate for physical infrastructure development projects. Program aid can be an effective way to provide macro-economic assistance for structural adjustment or for sector development in a country with substantial capacity for macro-economic policy analysis and program management. But neither the traditional program aid nor project aid instruments are fully effective in countries that have little financial or professional capacity for providing support for long-term institution-building efforts. New methods of combining the flexibility of program support, effective technical assistance, and sustained financial support for long-term development efforts must be sought. One innovation that might be effective is for the donor community to link the amount of external support to growth in domestic support (Table 6). This implies the development of a "formula" approach in which the size of donor contribution would be tied to the growth of domestic support. the formula should include a factor that adjusts the ratio of external to domestic support to take into account differences in domestic fiscal capacity.

Table 6: Illustration of a Funding Model for Agricultural Research Support

National Fiscal Capacity	Program Support and Assistance Level (millions of U.S. $)					
	Low		Medium		High	
	National Support	Donor Assistance	National Support	Donor Assistance	National Support	Donor Assistance
Low (40% Assistance	20	8	50	20	100	40
Medium (20% Assistance)	20	4	50	10	100	20
High (10% Assistance)	20	2	50	5	100	10

Country-Level Research Support Group

A second alternative might take its lead from the experience now accumulated with the CGIAR model and the various donor consortia that have been organized to co-ordinate assistance to some of the larger aid recipients. This means creating country-level Research Assistance Support and Implementation groups, chaired by the chairman of the natural agricultural research council or the director of agricultural research. The support group would need to have relatively long-term program plans for the development and operation of the national agricultural research system. To produce and continuously update this program, the national research system may require external assistance, but in general the program should be the product of indigenous experts in agricultural science and development. To help protect the program from the vagaries of political change, its focus would be on long-term agricultural research needs and goals and on the incremental steps required for implementation.

It is expected that the long-term program development and the priority setting would be done through an interactive process with the support group. Once the program has been accepted, donor members of the support group, it is hoped, would collectively agree with the host country to help provide the components essential to the execution of the *program as a whole*. The host country, in turn, would assume the responsibility for moving its national research program along the agreed-upon development path. Initial commitments might be for three to five years subject to annual review and to course corrections suggested by the analysis and feedback from actual experience.

Use of an institution such as a support group has the potential of helping the country avoid many of the pitfalls of the project mode while retaining several of its desired attributes. Donor identity could be retained by relating grants to components of the agreed-upon overall program. These could even be called projects if, for administrative purposes, it were so desired. The support group, like CGIAR, would likely involve bilateral grants developed in the framework provided by the forum of multiple donors and the host country. The impersonal process of contributing to a common fund is not envisioned. However, this would not preclude "incentive funding" of a formula type. At the same time, the danger that a single donor would dominate the priority-setting process, or that essential program components would be ignored, would be minimized.

The support group idea has several other potential advantages. (a) It would contribute to building a national constituency by focusing from the onset on the essential ingredient of viability. The donors, for example, might agree to increase their contributions by some fraction of the rise that occurred in the real support provided by the nation involved. Or other matching provisions might be agreed upon to provide incentives for nurturing and cultivating national constituencies. (b) It would provide reasonable ocntinuity in support (commitments would be fairly long-term and subject to review and extension well in advance of termination dates) with less risk of the excessive program fragmentation frequently associated with narrowly defined project funding. (c) It would reduce the administrative and management load on the host country through the planning and review process the support group would follow. And (d) it would place donors in a position of genuinely complementing and supplementing one another *and* the national program rather than endlessly competing for "good investment opportunities."

The fact that such a support mode is often discussed but little used is evidence that implementation is not a simple, trouble-free task. The method is, however, being used successfully in Bangladesh and, somewhat more informally, in several other countries. An important element in its success in Bangladesh is that the support group meetings are chaired by the director of the Bangladesh Agricultural Research Council rather than by a donor representative.

A dialogue on donor assistance to national agricultural research programs was initiated by the World Bank in 1981. The dialogue has been continued by ISNAR in a series of meetings with directors of national agricultural research systems. It is imperative that these dialogues be continued. The issue of reform of agricultural assistance should be recognized as one of the most urgent items on the agenda.

References

Ardilla, Jorge; Trigo, Eduardo; and Pineiro, Martin. "Human Resources in Agricultural Research: Three Cases in Latin America." Instituto Interamericano de Cooperation Para La Agricultura, San Jose, Costa Rica, March 1981.

Evenson, Robert E. "Comparative Evidence on Returns to Investment in National and International Research Institutes." In *Resource Allocation and Productivity in National and International Agricultural Research*, pp. 237-64. Edited by Thomas M. Arndt, Dana G. Dalrymple and Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977.

Evenson, Robert E.; Flores, Piedad M.; and Hayami, Yujiro. "Costs and Returns to Rice Research." In *Economic Consequences of New Rice Technology*. Los Banos, Laguna, Philippines: International Rice Research Institute, 1978.

Hadwiger, Don. *The Politics of Agricultural Research*. Lincoln: University of Nebraska Press, 1982.

Hambridge, Gove. *The Story of FAO*. New York: Van Nostrand, 1955.

Kamien, Morton I., and Schwartz, Nancy L. "Market Structure and Innovation: A Survey." *Journal of Economic Literature* 13 (March 1975): 1-37.

Nagy, Joseph. "The Pakistan Agricultural Development Model: An Economic Evaluation of Economic Agricultural Research and Extension Expenditures." Ph.D. thesis, University of Minnesota, March 1984.

Pineiro, Martin, and Trigo, Eduardo. *Technical Change and Social Conflict in Agriculture: Latin American Perspectives*. Boulder, Colorado: Westview Press, 1983.

Plucknett, Donald L., and Smith, Nigel, J.H. "Reworking in International Agricultural Research." *Science*, no. 225 (7 September 1984), pp. 989-93.

Pound, G.S., and Waggoner, P.E. "Comparative Efficiency, as Measured by Publication Performance of USDA and SAES Entomologists and Plant Pathologists." In *Report of the Committee Advisory to the U.S. Department of Agriculture*, pp. 145-70. G.S. Pound, chairman. Washington, D.C.: National Academy of Sciences, 1972.

Ruttan, Vernon W. *The Asia Bureau Agricultural Research Review*. University of Minnesota Economic Development Center Bulletin 81-2, St. Paul, Minnesota, March 1981.

Ruttan, Vernon W. *Agricultural Research Policy*. Minneapolis: University of Minnesota Press, 1982.

Ruttan, Vernon W. "Reforming the Global Agricultural Research Support System. In *Issues in Third World Development*, pp. 405-17. Edited by Kenneth C. Nobe and Rajan K. Sampath. Boulder, Colorado: Westview Press, 1983.

Sehgal, S.M. "Private Sector International Agricultural Research: The Genetic Supply Industry." In *Resource Allocation and Productivity in National and International Agricultural Research*, pp. 404-15. Edited by Thomas M. Arndt, Dana G. Dalrymple and Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977.

Schmookler, Jacob. *Invention and Economic Growth*. Cambridge, Mass.: Harvard University Press, 1966.

United States. Agency for International Development. *Strengthening the Agricultural Research Capacity of the Less Developed Countries: Lessons from AID Experience*. AID Program Evaluation Report no. 10. Washington, D.C.: September 1983.

United Nations Development Programme, and the Food and Agriculture Organization of the United Nations. *National Agricultural Research: Report of an Evaluation Study in Selected Countries*. Rome: FAO, 1984.

Venezian, Eduardo L. "International Cooperation in Agricultural Research." In *Selected Issues in Agricultural Research in Latin America*, pp. 99-124. The Hague: International Service for National Agricultural Research, March 1984.

Wilson, Lawrence A. *Toward the Future: An Alternative Framework for Agricultural Research, Training and Development in the Caribbean*. St. Augustine: The University of the West Indies, February 1984.

World Bank. *Strengthening Agricultural Research and Extension: The World Bank Experience*. Washington, D.C.: September 1983.

Appendix: Studies of Agricultural Research Productivity

Ayer, H. "The Costs, Returns and Effects of Agricultural Research in Sao Paulo, Brazil." Ph.D. thesis, Purdue University, 1970.

Ayer, H.W., and Schuh, G.E. "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil." *American Journal of Agricultural Economics* 54 (November 1972): 557-69.

Barletta, N. Ardito. "Costs and Social Benefits of Agricultural Research in Mexico." Ph.D. thesis, University of Chicago, 1970.

Bredahl, M., and Peterson, W. "The Productivity and Allocation of Research: U.S. Agricultural Experiment Stations." *American Journal of Agricultural Economics* 58 (November 1976): 684-92.

Cline, Philip L. "Sources of Productivity Change in United States Agriculture." Ph.D. thesis, Oklahoma State University, 1975.

Davis, Jeffrey S. "Stability of the Research Production Coefficient for U.S. Agriculture." Ph.D. thesis, University of Minnesota, 1979.

Duncan, R.C. "Evaluating Returns to Research in Pasture Improvement." *Australian Journal of Agricultural Economics* 16 (December 1972): 153-68.

Evenson, R. "The Contribution of Agricultural Research in Pasture Improvement." *Australian Journal of Agricultural Economics* 16 (December 1972): 153-68.

Evenson, R. "International Transmission of Technology in Sugarcane Production." New Haven, Conn.: Yale University, 1969. Mimeo.

Evenson, R.E., and Flores, P. *Economic Consequences of New Rice Technology in Asia*. Los Banos, Laguna, Philippines: International Rice Research Institute, 1978.

Evenson, R.E., and Jha, D. "The Contribution of Agricultural Research Systems to Agricultural Production in India." *Indian Journal of Agricultural Economics* 28 (1973): 212-30.

Flores, P.; Evenson, R.E.; and Hayami, Y. "Social Returns to Rice Research in the Philippines: Domestic Benefits and Foreign Spillover." *Economic Development and Cultural Change* 26 (April 1978): 591-607.

Griliches, Z. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." *Journal of Political Economy* 66 (1958): 519-31.

Griliches, Z. "Research Expenditures, Education and the Aggregate Agricultural Production Function." *American Economic Review* 54 (December 1964): 961-74.

Hayami, Y., and Akino, M. "Organization and Productivity of Agricultural Research Systems in Japan." In *Resource Allocation and Productivity in National and International Agricultural Research*, pp. 29-59. Edited by Thomas M. Arndt, Dana G. Dairymple and Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977.

Hertford, R.; Ardila, J.; Rocha, A.; and Trujillo, G. "Productivity of Agricultural Research in Colombia." In *Resource Allocation and Productivity in National and International Agricultural Research*, pp. 86-123. Edited by Thomas M. Arndt, Dana G. Dairymple and Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977.

Hines, J. 'The Utilization of Research for Development: Two Case Studies in Rural Modernization and Agriculture in Peru." Ph.D. thesis, Princeton University, 1972.

Kahlon, A.S.; Bal, H.K.; Saxena, P.N.; and Jha, D. "Returns to Investment in Research in India." In *Resource Allocation and Productivity in National and International Agricultural Research*, pp. 124-47. Minneapolis: University of Minnesota Press, 1977.

Knutson, M., and Tweeten, Luther G. "Toward an Optimal Rate of Growth in Agricultural Production Research and Extension." *American Journal of Agricultural Economics* 61 (February 1979): 70-76.

Latimer, R. "Some Economic Aspects of Agricultural Research and Extension in the U.S." Ph.D. thesis, Purdue University, 1964.

Nagy, J.G., and Furtan, W.H. "Economic Costs and Returns from Crop Development Research: The Case of Rapeseed Breeding in Canada." *Canadian Journal of Agricultural Economics* 26 (February 1978): 1-14.

Pee, T.Y. "Social Returns from Rubber Research on Peninsular Malaysia." Ph.D. thesis, Michigan State University, 1977.

Peterson, W.L. "Return to Poultry Research in the United States." *Journal of Farm Economics* 49 (August 1967): 656-69.

Peterson, W.L., and Fitzharris, J.C. "The Organization and Productivity of the Federal State Research System in the United States." In *Resource Allocation and Productivity in National and International Agricultural Research*, pp. 60-85. Edited by Thomas M. Arndt, Dana G. Dairymple and Vernon W. Ruttan. Minneapolis: University of Minnesota Press, 1977.

Pray, C.E. "The Economics of Agricultural Research in British Punjab and Pakistani Punjab, 1905-1975." Ph.D. thesis, University of Pennsylvania, 1978.

Pray, C.E. "The Economics of Agricultural Research in Bangladesh." *Bangladesh Journal of Agricultural Economics* 2 (December 1979): 1-36.

Schmitz, A., and Seckler, D. "Mechanized Agriculture and Social Welfare: The Case of the Tomato Harvester." *American Journal of Agricultural Economics* 52 (November 1970): 569-77.

Scobie, G.M., and Posada T., R. "The Impact of Technical Change on Income Distribution: The Case of Rice in Colombia." *American Journal of Agricultural Economics* 60 (February 1978): 85-92.

Tang, A. "Research and Education in Japanese Agricultural Development." *Economic Studies Quarterly* 13 (February-May 1963): 27-41 and 91-99.

Wennergren, E.B., and Whitaker, M.D. "Social Returns to U.S. Technical Assistance in Bolivian Agriculture: The Case of Sheep and Wheat." *American Journal of Agricultural Economics* 59 (August 1977): 565-69.

In addition to the studies listed in Table 2, there have been several important research impact studies in which results are reported in a cost-benefit rather than an internal-rate-of-return format.

Bauer, L.L., and Hancock, C.R. "The Productivity of Agricultural Research and Extension Expenditures in the Southeast." *Southern Journal of Agricultural Economics* 7 (December 1975): 177-22.

Marsden, J.S.; Martin, G.E.; Parham, D.J.; Risdill, T.J.; and Johnston, B.G. *Returns on Australian Agricultural Research: The Joint Industries Assistance Commission — CSIRO Benefit-Cost Study of the CSIRO Division of Entomology*. Canberra: Commonwealth Scientific and Industrial Research Organization, 1980.

Purchase, H. Graham. "The Etiology and Control of Marek's Disease of Chickens and the Economic Impact of a Successful Research Program." In *Virology in Agriculture: Veltsville Symposium in Agricultural Research-I*, pp. 63-81. Edited by John A. Romberger. Montclair, N.J.: Allanheid, USMUN, 1977.