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THE ORGANIZATION OF CROP- AND ANIMAL-IMPROVEMENT RESEARCH IN THE LOW-INCOME COUNTRIES

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Public and private crop and livestock improvement research has long been an important activity in most of today's developed high-income nations. The United States has nearly a century of experience in building agricultural research institutions and an impressive record of productivity gains which are in substantial part the direct consequence of these research programs. A number of European countries have an even longer record in this regard and most other modern agricultural nations, including Japan, have also invested significantly in agricultural research programs over many years. The record of crop- and livestock-improvement research programs in the contemporary developing countries stands in sharp contrast to that of most developed countries. With the exception of research programs on sugarcane, tea, coffee, and rubber and, to a very limited extent on rice, virtually no long-term sustained research programs have been undertaken in these countries. Even today, after more than twenty-five years of post-colonial development efforts, many commodities of major economic significance are receiving virtually no research attention. The development of research institutions has been slow and difficult and it is probably fair to say that no really first rate national agricultural research institutions are in place in a developing country today.

Nonetheless, the post-World War II period has seen substantial development in this area. A large number of new research institutions have been established in many countries and the total research effort has expanded significantly. Table 1 summarizes the available data on investment in agricultural research and extension for regions, by level of development. While too aggregative for some purposes, it does serve to illustrate the major features of agricultural research investment. It shows rather clearly that the developing countries have place greatest relative emphasis on extension programs as opposed to research programs. If we were to add investment in rural development projects which have been especially important in recent years, the emphasis on programs designed to implement existing technology, rather than to produce new agricultural technology, would be even further accentuated.

The table also reflects the slowdown in the rate of expansion of the agricultural research system which occurred soon after 1969. While I lack explicit data after 1974, it would appear that, with the exception of the higher-income developing countries, particularly Brazil, the national agricultural-research program development has slowed substantially in this decade, both quantitatively and qualitatively. This has occurred despite prospective food-shortage warnings sounded at the 1974 World Food Conference of the Food and Agriculture Organization in Rome and the crisis atmosphere reflected in the high food-grain prices which prevailed from 1972 to 1975. It is a measure of the superficial nature of many national and international policy-making processes that the crisis atmosphere of the 1970s spawned so little in the way of long-term investment in measures to improve food-producing capabilities.

TABLE 1. EXPENDITURES ON AGRICULTURAL RESEARCH BY REGION 1951-1974

Region	1951	1959	1965	1971	1974
	Total Annual Expenditures in Millions of 1971 constant U.S. dollars				
Western Europe	130.0	172.3	407.4	671.0	733.4
Eastern Europe and USSR	132.2	365.2	626.8	818.0	860.5
North America and Oceania	365.7	540.0	805.9	1203.4	1289.4
Latin America	29.7	39.2	73.0	146.4	170.3
Africa	41.3	58.0	113.5	138.5	141.1
Asia	70.0	131.0	356.4	610.2	646.0
World Total	768.9	1305.7	2383.0	3587.5	3840.7
	Percentage of Total Expenditures in Industrial Sector Research				
Western Europe	12.6	12.4	11.7	10.8	10.8
Eastern Europe and USSR	7.5	7.4	8.1	8.3	8.3
North America and Oceania	28.0	28.3	26.9	24.9	25.4
Latin America	3.3	3.6	3.6	3.2	5.1
Africa	2.9	3.5	3.5	2.9	2.9
Asia	2.8	2.5	2.4	2.2	2.2
World Total	17.4	15.9	13.9	12.9	13.1
	Percentage of Total Expenditures in "Agriculturally Related" Scientific Research				
Western Europe	19.8	19.5	24.8	27.6	27.6
Eastern Europe and USSR	27.0	26.4	19.0	17.2	17.2
North America and Oceania	11.7	11.7	12.2	16.3	16.4
Latin America	9.2	9.2	11.5	14.1	14.0
Africa	6.7	5.8	6.9	9.2	9.2
Asia	19.8	18.9	23.3	25.9	25.9
World Total	11.3	17.2	13.3	19.9	20.5

EXPENDITURES ON RESEARCH AND EXTENSION AS A PERCENTAGE OF THE VALUE OF AGRICULTURAL PRODUCT BY PER CAPITA INCOME GROUP, 1951-74

Income Group	1951	1959	1965	1971	1974
	A. Percentage Expended for Agricultural Research				
I (> 1750)	1.21	1.26	1.80	2.48	2.55
II (1001-1750)	.83	1.19	1.95	2.34	2.34
III (401-1000)	.40	.57	.85	1.13	1.16
IV (150-400)	.36	.37	.62	.84	1.01
V (< 150)	.22	.28	.47	.70	.67
	B. Percentage Expended for Agricultural Extension				
I (> 1750)	—	.45	.52	.61	.60
II (1001-1750)*	—	.17	.22	.33	.31
III (401-1000)*	—	.26	.40	.46	.40
IV (150-400)	—	.67	.99	1.44	1.59
V (< 150)	—	.57	1.04	1.76	1.82

* EXCLUDING EASTERN EUROPE AND U.S.S.R.

Source: Boyce, J. and R.E. Evenson, Agricultural Research and Extension Programs, A.D.C., New York, 1975.

The development of the system of international agricultural research centers over recent years has clearly been a significant factor in the developing countries. The contributions of the International Rice Research Institute (IRRI) and The International Center for Wheat and Maize Improvements (CIMMYT) are substantial and well documented. The addition of these centers and the several newer centers to the developing country setting has been qualitatively and quantitively important.

It is, of course, impossible to know the level of technical and entrepreneurial support which might have been made available to national research programs had the international centers not been built. Supporters of the centers argue vigorously that most bilateral and multilateral aid agencies would not have provided funding to national research program development in the absence of the development of the centers. A study by Boyce and Evenson (1975) estimated that annual bilateral and multilateral aid to national agricultural research programs in the developing countries was approximately 55 million dollars (1971 price level) in 1959 and increased to a level from 80 to 100 million dollars by 1965. By 1971 this level had declined by 20 to 30 million dollars. In the early 1970's FAO increased its support of research programs and this level rose somewhat.

Boyce and Evenson note that the late 1960's and early 1970's were years of general retrenchment of institution building and technical assistance programs but concluded that the international centers diverted perhaps $20 million dollars per year from national program support in the early 1970's. The Consultative Group for International Agricultural Research (CGIAR) has, in building the centers system, achieved a net increase in agricultural research funding since the centers funding has been higher than this and is now approaching 100 million dollars per year.

The decline in technical and entrepreneurial assistance to national program development has been substantial since the late 1960's. Part of this has been due to retrenchment related to political factors in developing countries. It is difficult to say how much real diversion of scientists from national to international programs took place but it is fair to note that many of the international centers scientists and administrators were once actively assisting national programs.

The question of the state of development of national programs, it could be argued, was not so serious during the period of rapid expansion of the international centers activities. But now the centers system has reached a plateau. No substantial further development is envisaged over the next decade. Does this mean that bilateral and multilateral aid to agricultural research will no longer be expanded? The CGIAR virtually acquired property rights to funding for agricultural research during the centers expansion period. Will it now be content to husband these rights to maintain the centers at their present levels? If no institutional arrangements are available to induce an expansion of aid support to national program development the future development of agricultural research programs will rest with the developing countries themselves.

Below, I discuss some of the organization problems of further developing national agricultural research programs, given the conditions that many developing countries face. I do not deal directly with research management issues nor do I attempt to develop a detailed research-planning scheme.

I concentrate on four organizational dimensions: (1) research allocation by commodity, (2) environmental orientation or targeting or research programs, (2) a commodity versus discipline focus, and (4) scale and other relationships among research organizations. I attempt to discuss the problems created by the skills market in many developing countries.

National programs, will, of course, be at different stages of development and, accordingly, the appropriate strategy for expansion will differ by country. A set of common problems and issues, however, enables a fairly general discussion. In the discussion of the major organizational issues set out above, the following factors are assumed to be essentially given in the short-run although later I will also discuss these issues as being subject to change through policy:

1. Most national policy-makers will continue to opt for the quick payoff project and will continue to overestimate the ease with which agricultural technology can be transferred across producing environments. Research programs will continue to be under pressure to produce quick results and will more or less have to be organized within this policy environment.

2. Research-program expansion will have to be undertaken under severe skill-supply conditions. The availability of graduate student fellowships from the traditional granting agencies will not increase substantially and may, in fact, decrease. In a few countries, World Bank loan funds will be used to support graduate study in the United States. The progress toward indigenous capacity in developing countries to train scientists at the master of science level will be substantial but they will be very slow to develop capacity to train at the level of the doctorate.

3. Scientists will be subject to a fragmented market in most countries. Basic university or government salaries for scientists will be low and relatively sticky because of social pressures to keep them in line with the salaries of lower-ranking personnel. However, the demand by national and international agencies for the services of most highly skilled scientists will be high. International agencies, in particular, will continue to be willing to pay international salaries for short-term consulting services by agricultural scientists. In many cases, the demand for these services will be largely political in the sense that representation from poor countries will be valued. This will present a continuing problem for the research manager and entrepreneur in terms of achieving an environment where scientists are able to devote principal energies to the research task and where they have an incentive to maintain research skills and to acquire new research skills.

4. Development of the international centers will reach a plateau. Few or no new centers are likely to emerge in the next ten years. Existing centers will continue to have only peripheral linkages to national programs but will continue to serve as important training centers and, perhaps more importantly, as sources of genetic materials and scientific information of value to national programs.

A Note on the Literature on Research Productivity

I will not review at length the literature on the impact of research on productivity. It, for the most part, does not address organizational questions directly and is summarized in a number of places, particularly in the Airlie House papers now published by the University of Minnesota Press.[1] The issues of scale and interrelationships among research organizations are not examined in most of the empirical work on the topic. A number of papers, particularly those by Moseman and Hayami[2] are relevant, however, for they do show the importance of regionally coordinating research programs. The question of scale economies is a very complex one and involves not only the question of size of a single research institution, but of the relationships among institutions as well. My study (Evenson, 1968) did measure scale economies to U.S. State Agricultural Experiment Stations in the 1950s. My extension of this study to a later period, however, casts some doubts on whether scale economies did exist (Evenson and Welch, 1974).

The literature does tend to show that a number of different types of research institutions have been highly productive. The early U.S. experiment station system was productive for a period but then was subject to exhaustion of technology and appeared to be unproductive.

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[1]Arndt, T., Dalrymple D. and Ruttan, V. (Eds.) Resource Allocation and Productivity in National and International Agricultural Research, Minneapolis: University of Minnesota Press, 1977.

[2]in Arndt, Dalrymple and Ruttan, op. cit.

Similarly, many of the early developing-country experiment station systems appear to have been productive even though they were small, isolated from other scientific institutions, and relied on relatively low-level skills. Again, after a period of high productivity they appear to have in many cases slipped into low productivity.

The distinction between simply exploiting technology potential through adaptive research and both creating and exploiting technology potential is one that I find critical here. It appears that where a real technology potential exists a number of alternative institutional arrangements can exploit it. Thus, if technology potential is in some sense produced and delivered to dependent research institutions we may not have to be too concerned about the sophistication of the organization of the dependent institutions.

However, when we are dealing with research institutions which have some degree of independent capacity to produce technology potential (and to both exploit and export this potential to dependent institutions) we do have complex organizational questions. These involve communication between scientists and issues of disciplinary organization. There are substantial scale economies that may emerge but a number of related issues also become important. The establishment of identifiable "frontiers" both in technology and of related science and the utilization of high-level scientific skills becomes important.

To date, the economic literature has little to say about these complex issues. The *ex post* studies have tended to be based on short historical periods and have not always attempted to control for the levels of technology potential in judging the productivity of research. *Ex ante* studies, on the other hand have tended to evolve strictly as simple project- and programevaluation techniques. They presuppose that the research system has developed imaginative proposals and thus miss a critical part of the research process.

Research Allocation by Commodity

Perhaps the most tangible dimension of agricultural research allocation and organization is its commodity orientation. An optimal allocation of research effort does not necessarily lead to a distribution of research resources among commodities proportional to the economic importance of the commodities. There are, however, reasons to expect that in the long run, such an allocation rule might be a reasonable approximation to an optimizing rule. Suppose that nature were "plastic" in yielding her secrets, in the sense that the expected discovery function (showing the probability of discovering crop or livestock improvements as a function of research effort) was the same for each commodity (or commodity sub-group). Under this condition, resources would be optimally allocated if the same proportion of the economic value of each commodity were devoted to research.

Before turning to an examination of factors which produce a nonplastic nature, let us consider the summary data in Table 2 on the allocation of research by commodities in the developing countries. This allocation is far from optimal. Several commodities of major economic importance are receiving only minimal research attention. The root crops, in particular, are receiving very little attention. In general, the commodities evidencing the highest research attention are also the commodities on which research has proceeded for the longest period.

One of the reasons for nonplasticity may be that research programs on neglected commodities have relatively low productivities in their early years. It may take several years to collect and classify germ plasm and to make physiological and pathological studies to develop the basis for a productive breeding program. The time lag between investment and payoff

TABLE 2. Estimated Percentages of Product Value Expended on Research for Major Agricultural Commodities Produced in the Developing Countries of Asia 1959 and 1975

Commodity	Approximate Share of Total Commodities in 1974	Percent of Product Value Expended on Research by National Programs in South, Southeast, and East Asia (excluding Japan and China)	
		1959	1974
1. Rice	23.1	.05	.12
Upland	(3.7)	.02	.03
Shallow Depth	(8.5)	.06	.15
Intermediate Depth	(9.0)	.04	.06
Deep Water	(1.9)	.02	.03
2. Livestock and Products	20.5	.06	.11
Dairy	(12.0)	.04	.08
Others	(8.5)	.08	.25
3. Pulses	5.6	.02	.06
4. Sugarcane	4.5	.10	.24
5. Roots and tubers	4.4	.01	.03
6. Millets and Sorghum	4.4	.04	.11
7. Wheat	3.9	.08	.23
8. Groundnuts	3.1	.02	.04
9. Oilseeds	2.7	.02	.04
10. Cotton	2.7	.43	.58
11. Tobacco	2.0	.04	.06
12. Maize	1.7	.06	.12
13. Vegetables	1.6	.05	.10
14. Rubber	1.4	.40	.57
15. Tea	1.4	.10	.15
16. Bananas	1.2	.01	.02
17. Coconuts	1.1	.01	.03
18. Jute	1.1	.04	.08
19. Coffee	1.0	.05	.10
20. Spices (Pepper, etc.)	1.0	.10	.15

Source: Based on Boyce and Evenson, 1975.

will thus be longer for the neglected commodities than for those crops on which research has been in progress for many years. It is not necessarily the case, however, that the "internal rate of return" realized to investment in research on neglected crops in the early stages is lower than it is on more established crops. The longer gestation period combined with a high policy discount rate (i.e., valuing short-term gains most highly), however, does provide an explanation for the tendency to invest relatively little in the neglected crops.

It is likely then that the short-term expected-discovery function will differ among commodities which have and have not gone through the "groundwork" stage. It will also differ according to the degree of "exhaustion" of what we might term the distribution of potential discoveries. This distribution is determined by the groundwork or basic research. In the early stages of work on a commodity, groundwork research is required to create potential. At later stages in commodity research, this potential will become exhausted by plant breeding and agronomic research. The capacity to create new potential then becomes critical. Indeed, this capacity is the key to the development of a first-rate research system. And where this capacity exists, nature tends to be plastic. Technology potential will tend to be maintained in all commodities creating an expected technology discovery function which may be quite similar in each commodity.

A mature, fully developed research system then must allocate research effort both to technology discovery in each commodity and to the creation of technology potential. For the most part, the national research programs in most developing countries have not emphasized the creation of technology potential either of the initial type or of the continuing type. Nor for that matter have the international agricultural research centers, although they have made some contributions here. The developing countries are at a particular disadvantage in the building of capacity to create technology potential because of their limited supply of highly trained skills and because of the nature of the market for such skills. The international centers, however, are not subject to these limitations and have a clear comparative advantage in the creation of technology potential. I will return to this point later.

Given the limited skills and other problems, the same kind of resource allocation among commodities in the developing and developed countries would not be expected. This is borne out by table 3 which reports a congruity index showing the association between research expenditures and commodity importance[1]. The index shows a closer association between commodities and research emphasis in the more developed countries. It also shows a closer matching over time. This suggests a general consistency of national government policy with conditions in developing countries. It does not imply optimal policy-making, however, by national and, particularly, not by international programs. The failure to establish technology potential in the neglected crops appears to be the most serious flaw in research-system development from the commodity-orientation perspective.

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[1] The index is constructed as: $I = 1 - \sum_i (C_i - R_i)^2$ where C_i and R_i are the shares of the ith commodity in total agricultural product and total agricultural research respectively. Thus an index of one means a perfect association between the research mix and the commodity mix.

TABLE 3 COMMODITY RESEARCH CONGRUENCE BY PER CAPITA INCOME GROUP

Income group	1959	1965	1971
I (> 1750)	.832	.810	.905
II (1001-1750)	.680	.827	.850
III (401-1000)	.769	.830	.833
IV (150-400)	.734	.830	.819
V (< 150)	.627	.705	.748

Source: Boyce & Evenson 1975.

TABLE 4 . AGRICULTURAL RESEARCH INVESTMENT BY GEO-CLIMATE ZONE

Geo-climate Zone	Expenditures (millions 1971 $)			Number of Sub-regions	Expenditures (thousand 1971 $ per Geo-climate Sub-region)		
	1959	1965	1971		1959	1965	1971
Tropical	62.6	135.2	217.0	65.37	977	2068	3319
Tropical Highlands	19.0	38.4	33.7	8.72	2176	4408	3806
Desert	13.7	27.3	35.0	23.94	571	1141	1464
Subtropical	67.0	147.8	244.0	24.18	2772	6114	10089
Pampean	48.7	90.8	145.4	45.30	10757	20044	32008
Mediterranean	100.8	159.4	265.3	75.74	1331	2110	3503
Marine	353.4	665.5	092.6	38.52	9174	17276	23431
Humid Continental	332.2	649.7	985.9	21.78	15250	29830	45266
Steppe	348.5	557.5	794.0	24.54	14201	22718	32359

	Scientist Man-Years per Geo-climate Sub-region			Standard Publications per Geo-climate Sub-region			
	1959	1965	1971	1951	1959	1965	1971
Tropical	52.6	100.0	180.2	9.0	12.4	18.4	21.6
Tropical Highlands	103.7	193.7	259.7	15.7	14.8	23.2	31.1
Desert	43.1	87.9	122.6	4.6	6.7	10.2	14.6
Subtropical	146.4	268.0	442.2	31.3	35.8	45.9	48.7
Pampean	370.2	595.1	947.9	92.9	100.0	106.6	81.7
Mediterranean	58.2	92.3	130.7	8.1	10.1	13.8	15.9
Marine	501.6	850.0	1133.2	45.1	62.2	92.6	111.5
Humid Continental	912.2	1558.7	2134.9	62.1	92.4	133.4	150.8
Steppe	581.6	.1000.3	1307.9	51.8	88.0	129.1	153.5

Source: Boyce and Evenson, 1975.

Resource Allocation by Environmental Region

The previous commodity-orientation discussion is incomplete in major respects. First, each crop is grown in a range of producing environments. Rice environments vary greatly from upland conditions to deep-water conditions. Sugarcane producing environments are much less variable. The environments vary not only by location but also over time in the same location. Second, agricultural technology for all commodities has some degree of sensitivity to some or all environmental components. The agronomy literature generally refers to these as geno-type environmental interactions. They differ in strength by commodity. A geno-type (variety) is said to be stable if it has a low degree of sensitivity to changes in environment over time in the same location. It is said to be adaptable if it has a low degree of sensitivity to environmental differences across locations.

One of the factors in the development of the modern wheat varieties at CIMMYT and, to a much lesser extent, the modern rice varieties, has been the selection for adaptability or for low sensitivity to environmental differences. The failure of the CIMMYT maize programs to produce widely adopted new varieties is in large part due to the inherently limited scope for selecting for adaptability in maize.

Natural biological selection processes over the centuries produced an immense variety of plant and animal species, each having a comparative advantage in an environmental "niche." This is due of course to geno-type environment interactions. Man's efforts to improve commercial crop and animal species have only partially overcome the problems created by these interactions. Selecting for adaptability has its price in the sense that some other traits of economic value have to be sacrificed to obtain more adaptability. Consequently, agricultural research programs have long been organized around "target" environments (such as soil types, rainfall and days to maturity). The economic value of the expected increased product will be maximized for n greater than 1. Furthermore, a research program designed to produce improvements for only one target environment or a set of closely related environments, even if quite successful, will produce improvements which may be transferrable only to nearby or similar environments. If technology-environment interactions are strong it is quite possible for steady improvements, for example, in maize technology suited to the U.S. Corn Belt to have no value at all for maize producers in the tropics.

I will not attempt to model the optimal targeting principles in this paper. They have not been fully developed in any case. However, certain intuitive statements can be put forth:

1. The higher the degree of technology-environment interaction in the commodity, the more target environments there will be.

2. The higher the degree of scale economies to research organization, the fewer the number of targets and the more stress on adaptability there will be. Conversely, if there are few economies of scientist association and the cost of pursuing multiple-target programs within an experiment station are relatively low, many targets will be adopted.

3. The more variable are producing environments over time, the fewer the targets and the more valuable will adaptability be, provided that the traits of stability and adaptability are highly positively correlated.

4. From an international perspective, it will in general not be wise to totally neglect any producing environments unless they are very small. An international center attempting to produce technology for regions where national programs are weak will stress adaptability and concentrate on fewer targets.

There is little doubt that even within commodities the allocation of research funding by environmental region is far from optimal. Some of the dimensions of this can be seen in table 4 which shows research investment levels by geo-climate region. The international centers, particularly CIMMYT, have attempted to respond to the failure of national programs to cover major environmental zones, but as a practical matter they cannot be expected to fully accomplish this task. Indeed, the problem in rice research is sufficiently important that there is a justification for perhaps one or two more international centers. The differences between upland, shallow-water, and deep-water environments are so significant that these types of rice can be regarded as different commodities (see table 2). It is unrealistic to expect one institution to be able to function effectively in dealing with this much complexity.

Single Commodity, Multiple Commodity, and Discipline Orientation

Two matters pertinent to the question of organizing research institutions along single commodity, multiple commodity, or mixed commodity-discipline lines have been discussed briefly. The first was the choice between investment simply in technology-producing research programs and investment in more complex programs which seek both to discover technology and to create technology potential. The second was the environmental scope of the research institution. A third is the complementarities between scientific-skill production and research.

It is sensible for a national agricultural research program in its earliest developmental stage to concentrate its resources on the highest payoff projects. Given the scarcity of high-level scientific skills, it is natural that research programs be oriented to the exploitation of existing technology potential. In this early stage, no substantial capacity to create new technology potential exists and the system might be termed a simple adaptive system.

As resources are expanded and experience gained in the management of research programs, the development of the capacity to create technology potential becomes feasible. The incentive structures facing most less-developed countries, however, have retarded the development of a technology-potential capability and have instead pressed for an expansion of the simple adaptive system. This retardation has been due to:

1) The heavy reliance of national research programs on international aid and developed-country institutions for scientific skill production.

2) The policy milieu supported by international agencies which admonishes the national programs to concentrate on simple adaptive research--and correspondingly has not aggressively supported the building of research institutions capable of creating technology potential.

3) The role of the international centers in providing technology potential to the national programs.

4) The disrupted skills' markets which make the building of technology-potential capacity difficult.

In the simple adaptive stage, there are relatively few economies of association across commodities, but they are potentially important across disciplines. At the same time there are good reasons to pursue a fairly large number of environmental targets in simple adaptive systems. These incentives lead to a system with small single-commodity experiment stations. Provided that technology potential is maintained, these simple adaptive systems can be productive and can make good use of low-level skills.

This model of research-system development is fairly prevalent in many poor countries. India, for example, had developed more than 500 experiment stations by about 1960. The major problem with simple adaptive programs is that some means of delivering technology potential to them must be available to make them productive. The failure of many national programs to build the capacity to deliver technology potential has reduced the productivity of these simple adaptive systems. The international agricultural research centers have delivered technology potential to these systems in rice and wheat and possibly maize but one should recognize their limitations in this respect.

At the international center level, the single-commodity model also makes sense given the complexity of dealing with the broad range of producing environments and the concern both with producing technology for them and delivering technology potential to them (this latter concern has not been stressed enough, however). Given these objectives, it makes sense to stress the economies of association across disciplines.

Investment in systems capable of producing technology-potential leads generally to a hierarchy of central and branch experiment stations. The central experiment stations concentrate on the technology potential and, generally, find the disciplinary focus most productive. The critical aspect of organization to produce technology potential is the juxtaposition of commodity-orientation research programs and scientific-discipline orientation. The history of technology in many fields indicates that technology search conducted in isolation from organized scientific disciplines is subject to exhaustion. It also indicates that scientific research conducted in isolation from technology search is unproductive in that its "products" are often not valuable in terms of creating technology potential.

The U.S. State Agricultural Experiment Station research organizations represent one model of integration of technology research and scientific disciplinary research. This model suggests that the central experiment stations will find that a multi-commodity focus with a disciplinary organization will be most productive. They will also be subject to economies of scale. But the overriding factor in the productivity of such stations will probably be the extent to which a genuine scientific and technological frontier exists and is maintained by the scientists in the system.

It may be argued that it is unrealistic to develop these sophisticated agricultural research programs in low-income countries. Such systems are costly and demanding in terms of skilled personnel. Many efforts to develop sophisticated research programs have failed because of the difficulty of maintaining skills. However, the case for investment in building such systems becomes quite feasible when the costs of importing skills via graduate training abroad and the complementaries between graduate training and scientific research are considered. The development of first rate research and graduate training centers in the developing countries is costly to be sure, but the strategy of importing these skills is probably even more so.

National and International Center Relationships

The comparative advantage of the international centers is derived partly from the limitations of national systems and partly from real comparative advantages. In a setting where national research programs have not developed the capacity to pursue adaptive research, an international center will be able to produce technology suited to some of the neglected environments. For wheat and rice, CIMMYT and IRRI have, by reason of their genetic resources and systematic breeding programs, exploited technology potential developed partially in temperate-zone conditions, and they have been able to provide new technology of great economic value to some of the producing regions of the developing world.

It surely is the case that one of the lessons to be derived from the wheat and rice experience is that a concentrated program of crop improvement by highly qualified scientists can quickly exploit scientific potential. But other lessons are there as well. One is the role of IRRI and CIMMYT in creating technology potential for a number of national research programs. This has been a very important part of the total contribution of these two centers. Most of the modern varieties of both wheat and rice are what might be called joint products of national and international centers in that IRRI and CIMMYT genetic material was utilized by national breeding programs to produce locations specific varieties.

The role of the international centers is to some degree illustrated in table 5 which reports measures of research-induced shifts in Asian rice-supply functions associated with rice research. The table portrays the extraordinary gains associated with the green revolution after 1966. It also shows that the poorly organized national research programs were producing some supply shifts prior to 1966. These supply shifts were of sufficient size to yield an internal rate of return to national rice-program investment of 39 percent in the pre-1966 period.

The really significant aspect of the table, however, is not that the investment in IRRI produced a major impact (84 percent internal rate of return), but that it made the national programs in rice more productive. The internal rate of return to national program investment rose to 74 percent in the 1965-75 period and national programs contributed the bulk of the green revolution shifts.

In my judgement the programming of most of the centers is somewhat misplaced at present. The opportunity to repeat the wheat and rice exper-

Table 5 Estimated Annual Supply Function Shifts Attributable to Rice Research Programs

(Annual Shifts Expressed in Percentage Units)

	Period			
	1959-60	1961-65	1966-71	1972-75
Attributable to National Plant Breeding and Agronomy Research	.093	.151	.461	.284
Attributable to National Related Agricultural Science Research	.137	.212	.459	.423
Attributable to HYV's Developed at IRRI	-	-	.419	.387
Attributable to HYV's Developed Independently in National Programs	-	-	.066	.182
Attributable to HYV's Developed in National Programs with one IRRI parent	-	-	.122	.161
Total Shift due to Research*	.157	.319	1.528	1.430

*The contribution of research occurs partly in countries other than the country doing the research. Hence, the total supply shift is not the sum of the parts.

Note: Adapted from the "Low" estimates reported in Table 9 of Evenson, R.E., P. M. Flores and Y. Hayami, "Costs and Returns to Rice Research" IRRI Resource Paper No. 11 for the Conference on Economic Consequences of New Rice Technology.

ience is just not there for most other crops. The experience with maize demonstrates the powerful limits placed on international programs by genotype environment interactions. Few other commodities offer the backlog of research work in developed countries that existed in wheat and rice (though sorghum and barley are possible candidates). For the most part, other major commodities of concern to the centers and to national programs are what I have termed "neglected" commodities. The root crops, pulses, and other tropical crops have generally not gone through the groundwork stage of germ plasm collection and classification and physiology and pathology studies.

I would argue that, for the short term, the most important comparative advantage of the international agricultural research centers is in the explicit pursuit of groundwork research on neglected crops. This is, of course, being done in a number of them. What I am suggesting here is that groundwork research be more clearly and explicitly taken as an objective of the international centers. Furthermore, I would argue that the international system should carefully examine the options for initiating work on more commodities and that their staffing and programming be organized accordingly. Ways should also be explored to design research programs on some of these commodities which can be undertaken by the strongest national research programs.

This groundwork research is part of the more general comparative advantage that the international research centers have in producing technology potential. This comparative advantage also extends to the production of technology potential in the more mature research fields. Here we see little aggressive action by the international centers.

It may be that a single commodity institution with "worldwide" concerns is not capable of either doing or inducing the basic work to create new technology potential. More complex organizations may be required. Nonetheless the international centers could provide substantially more guidance in terms of inducing work in other institutions than at present. The history of the U.S. agricultural experiment Station would indicate, however, that it is not until a substantial period of exhaustion has set in that institutional change in the form of efforts to develop technology potential take place. It would be very useful if the policy-makers in the international system were able to short cut this historical process.

It now is quite clear that there are further comparative advantages to an international center in terms of the collection and classification of genetic resources and their systematic dissemination. This extends to other forms of knowledge as well. These centers can perform a valuable service in facilitating exchange of relevant scientific materials. They are also emerging as centers for crossing and coordinated screening and testing of plant materials for different environmental targets.

The international agricultural research center then has a place in the scheme of things even as national programs develop more highly. One area where such centers can make a major contribution in terms of contributing to the efficient design of commodity-research programs is in the development of a systematic classification of producing environments, by commodity. Such a classification, with an appropriate mapping, would enable the identification of neglected environments and neglected commodities with more clarity. It would also allow for more systematic environmental targeting of international genetic material.

Prospects for More Aggressive Research Program Development

The Boyce and Evenson study referred to at several points in this paper, is the only source of comprehensive data on international agricultural research investment. The fact that no international agency has seen fit to compile more complete and systematic data reflects the low priority given to research program development. In the introduction to this paper I indicated that the prognosis for aggressive support for building more effective research programs in most of the developing governments was not good. I also raised the possibility that international aid funding would not be utilized to aid major national program development but would instead be utilized to maintain the present international centers system. I will attempt to discuss these questions more fully in this concluding section.

For purposes of this discussion, it will be useful to characterize alternative research program development sequences. These sequences have a fair amount of historical validity and will allow distinctions to be made between different groups of countries.

A. The Early "Pioneering" Institution Development Stage

In this stage very few well-trained scientists are available to the system. The few scientists with high levels of training are often taken up with administrative and organizational tasks. Scientific skills are quickly lost as the incentives and opportunities for maintaining them do not exist. National governments are seldom willing to commit scarce resources to experiment station development in this stage and certainly do not commit resources to graduate study support. It is quite critical that international aid agencies support this pioneering phase and enable the beginnings of scientific professional development so that an awareness of the contribution that research programs can make can emerge within the public decision-making process.

At the beginning of the post-World War II development period, only a handful of the contemporary developing countries had passed through this phase. The Boyce-Evenson data suggest that Brazil, Colombia, Mexico and possibly Venezuela in Latin America had done so. Only the UAR and possibly Nigeria in Africa and Turkey, India and possibly Malaysia, the Philippines, Taiwan and South Korea in Asia had passed through this stage at that time. Many of today's developing countries have now passed through this stage and most have had substantial aid funding and aid stimulus which has enabled them to do so. But the record is far from good. Even today Paraguay and Bolivia in South America, several of the smaller countries in Central America, most of the newer African nations and Afghanistan, Nepal Burma and much of Indochina are probably still in this early stage.

B. The Simple Adaptive System Stage

In this stage a systematic building of simple adaptive research institutions takes place. Developing countries depend heavily on aid resources for building and equipment support and for advanced graduate training. In the later phases of this stage some capacity for graduate training may exist, but virtually all Ph.D. level training takes place in developed country centers with international aid support. A proliferation of research stations begins to emerge in this stage as a serious effort is made to expand the system under the constraint of low skill levels among scientists. Many of the scientists with advanced training are, however, able to make very significant contributions in this stage and even though many of the research stations are isolated and weak from a scientific point of view, they can be highly productive by exploiting some locally available technology potential.

C. The Advanced Adaptive System Stage

In this stage a few research institutions emerge as main research stations with a responsibility for feeding technology potential to "branch" simple adaptive stations. They have a limited capacity to do so because the development of this capacity is extremely demanding. It requires not only financial and technical aid but a very strong indigenous entrepreneurship and a national program financial support. During this stage a host of problems centering on the nature of the market for skill tends to emerge. These problems along with basic limitations in aid support mechanisms make it extremely difficult for countries to move into the next stage.

D. The Technology Potential Capacity Stage

This stage is relatively advanced and for practical purposes no developing country has yet achieved it. Some formerly poor countries (Israel, South Korea, Taiwan and Brazil) have probably reached the early phases of the stage, but one has to be impressed with the apparent difficulties of moving beyond the simple and the advanced adaptive stages. This technology potential stage requires the development of genuine research frontiers and strong professional orientation of scientists, as well as an administrative and organizational structure to orient the scientists toward the solution of real problems. In practise it is associated with the development of capacity to provide strong Ph.D. level graduate training.

The Boyce-Evenson data, as noted, indicate that a number of countries have not yet moved beyond the pioneering stage in their development. Since aid agencies play a dominant role in this stage there is substantial cause for critical comment here. Surely there is strong economic justification for aggressive support to bring virtually every country in the world at least through this developmental stage. International agencies have much valuable experience in aiding other developing countries to achieve this stage and should not find it difficult to support the remaining countries in this connection.

It is difficult to say how many developing countries have managed to move beyond the simple adaptive stage and into the advanced adaptive stage. It would appear that Mexico and Colombia and possible Chile and Venezuela have reached the advanced adaptive stage in Latin America (Brazil and Argentina are somewhat more advanced although at any given time political factors effect the status of any of these countries). In Africa, Kenya, Nigeria and the United Arab Republic have probably also reached this stage. In Asia, Taiwan and South Korea and to a somewhat lesser extent, Malaysia, the Philippines and Thailand have made progress. India and Pakistan have also developed relatively advanced research systems.

It is, of course, true that aid agencies have contributed in a major way to the progress made in most of these developing countries. If I am critical of international agencies for not developing more aggresive support mechanisms, I am implicitly criticizing national governments as well. I do not, however, find the overall record of international agency support to be consistent with the very substantial evidence that has emerged measuring research productivity. Surely the extraordinarily high rates of return indicated for research investment even if discounted heavily have call for far more agressive programs in this area than have actually been undertaken.

As I have already noted, the supporters of the international centers system argue that aid agencies have a very limited interest in funding research programs and that the flow of funds to the building of the international centers represented no significant diversion away from national program funding. I believe it reasonable to conclude that some diversion of funding and entrepreneurship did occur. However, this diversion, even if quite substantial, does not provide a full explanation for the failure to develop more agressive programs. One has to turn to two further factors for further insight into this question. The first is the relationship between the supply of scientific skills and research institutional development. The second in the skill requirements for effective support.

National governments have relied so heavily on international aid for support of graduate training that they have lagged in the development of an indigenous capacity to produce scientific skills. The development of an advanced research program requires, for most larger countries, substantial numbers of trained scientists. In addition to the demand from the scientific system itself there is often a demand for scientists in administrative and planning roles. As the costs of importing skills via graduate studies abroad have risen, the constraints on institution building become more severe. This problem is then further exacerbated by a phasing out of international support for graduate study.

To some extent this problem is part of the more general problem of achieving or inducing a transition from international aid support to a strictly indigenous institutional program. This is not an easy transition but it is in the end one that must be made. It is true that aid programs will eventually run into the "pushing on a string" problem. Many institutions in the developing countries have been so dependent on a donor agency that they have not developed indigenous leadership and entrepreneurship or a capacity for self determination.

The matter of the capacity of international agencies to provide real technical support in the more advanced institutional development stages is also a real one. The building of outstanding research institutions in developed countries required strong influential and leadership abilities in order to be achieved. Many of the institution building programs of the 1950s and 1960s in developing countries were frustrated by problems associated with the lack of strong local entrepreneurial capacity. Today, however, it appears that in a set of selected institutions throughout the developing world a significant entrepreneurial capacity exists. The basis for support of national programs relying on indigenous entrepreneurship now represents a very realistic approach on the part of donor agencies. The World Bank in its operations has already provided substantial funding of development of agricultural research programs in a number of countries and this appears to date to have been quite successful. Other development agencies could well begin to introduce loans for the building of laboratories and equipment as well.

Recent expansion of general international programs directed toward agricultural development have been significant even though they have had little direct impact on research system development (USDA ERS 1977). The recent World Food and Nutrition Study (National Academy of Science, 1977) reports a well-reasoned set of recommendations calling for more aggressive action by the United States in support of research. As these initiatives are developed further we may see significant new programs for research support. I have not been encouraged by developments to date but do not wish to be heavily pessimistic.

A number of institution support programs somewhat modeled after the institution building efforts of USAID in the 1950's and early 1960's will probably be undertaken (CIC, 1968). They will serve to bring many more institutions and systems into the single adaptive stage and will enable others to move into the advanced adaptive stage. Such programs will generally have relatively high pay-offs and should be pursued aggressively. I would argue, however, that a specific program designed to enable a few agricultural research and graduate training centers to develop as strong graduate teaching centers will have a very high pay-off. More importantly it will allow more rapid and effective development of adaptive systems.

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