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The Development and Adoption of High-Yielding
Varieties of Wheat and Rice in Developing Countries

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 High-yielding varieties (HYVs) - also known as modern varieties (MVs) - of wheat and rice have spread more widely, more quickly, than any other technological innovation in the history of agriculture in the developing countries (DCs). First introduced in the mid-1960s, they occupied about half of the total wheat and rice area in the DCs by 1982-83. Their area has increased since that time and will undoubtedly continue to grow in the future. The purpose of this paper is to give a brief idea of how all this came about, document the spread of the HYVs, and outline what remains to be done.

The Varietal Improvement Process

Varietal improvement of food crops through systematic breeding is a relatively new process in most developing nations. Colonial powers emphasized research on export crops rather than food crops for domestic consumption. Relatively few improved varieties of wheat and rice were developed or introduced from other nations prior to the 1950s.

Grain
 Thereafter the pace of research began to increase. The Rockefeller Foundation became particularly active in encouraging varietal improvement programs, first in Latin America, and then in other developing nations. They joined forces with the Ford Foundation to establish the International Rice Research Institute (IRRI) in the Philippines in 1960, and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico in 1967. Three other international agricultural research centers (IARCs) were subsequently established which also worked on rice or wheat (CIAT in Colombia, IITA in Nigeria, and ICARDA in Syria).

AAEA paper, 1985

At first the Rockefeller program in Mexico (headed by Norman Borlaug) developed varieties of conventional height, but soon ran into a yield ceiling because the varieties lodged or fell over when they were heavily fertilized. Improved rice varieties exhibited the same problem. In order to reduce lodging, attention turned to developing shorter varieties.

Semi-dwarfs filled the bill. They also generally had some other desirable characteristics - particularly earlier maturity and photo-insensitivity. It was possible to breed in other desirable qualities such as increased insect and disease resistance. Thus the result was a product which incorporated a number of improved characteristics and provided the potential for substantially increased yields. Realization of this potential depended on the adoption of a package of improved cultural practices.

Development of the Semi-Dwarfs

Short height was the necessary, if not sufficient, condition for higher yields. It also provided the basis for ready identification and hence reporting of the HYVs. Where did it come from?

Short varieties of wheat and rice, the products of natural mutations, were observed in Japan as early as 1873. As the availability of fertilizer increased late in the 1800s and in the early 1900s, their use expanded. Shinriki rice was a particular example. Few short varieties, however, were what we now know as semi-dwarfs (which carry one or two major genes for reduced height).

Wheat varieties known to have semi-dwarf genes emerged in Japan early in this century. One variety served as ancestor of some semi-dwarf

Italian wheats, which in turn have been used as parents in some Near Eastern countries and in China. Another variety was used to breed Norin 10 in Japan in the 1930s. Norin 10' was brought to the United States after World War II. It was crossed with Brevor at Washington State University; the offspring was utilized in domestic breeding programs and sent to Borlaug in Mexico. He used it to develop a range of semi-dwarf varieties which came into widespread use in the 1960s.

Semi-dwarf rice followed a different pattern. A variety from southern China, Dee-geo-woo-gen (DGWG), found its way to Taiwan early in the century. Before WW II, several semi-dwarfs were grown. After the war the first semi-dwarf developed through breeding, Taichung Native 1, was released. When IRRI was established in 1960, a number of the semi-dwarfs were used in the early crosses. DGWG became one of the parents of the first variety to be released, IR8. The People's Republic of China (China) developed a series of semi-dwarf varieties independently of IRRI (but later made use of IRRI crosses as parents, especially for hybrid varieties - which accounted for about 25% of the rice area in 1984).

Since these early efforts, other varieties have been found which carry the dwarfing characteristic. Induced mutations provided additional sources. But virtually all of the semi-dwarfs from the developing nations (including China) have been found to carry the same dwarfing genes.

Semi-dwarfs are most appropriate in irrigated or well watered conditions. They have not proved as well suited to other cultural conditions - particularly to upland or dryland rice culture where taller varieties are better adapted. Even there, however, the more productive varieties are often shorter than their predecessors.

The Pattern of Research

The varietal improvement process has now fallen into a general pattern. The IARCs, utilizing the immense wealth of genetic resources in their hands, make a large number of crosses each year (IRRI makes some 4,000 crosses and in 1985 published a listing of its first 50,000 crosses). The more appropriate lines are circulated worldwide through international testing networks. Scientists in DCs select the most promising lines for use in their country. Some are released directly as varieties by the DCs (over 120 to date in the case of rice) while others are used as parents in making further crosses. None of the IARCs release or name finished varieties as such.

As a result, virtually all of the HYVs in use in the DCs (except as noted for China), have a cross made at an IARC included in their ancestry. This heritage may not be immediately evident, particularly where the lines or crosses are given local names, but it can usually be traced if one checks far enough. Increasingly, varieties from other countries are used as parents, but these too usually have some IARC ancestry.

The resulting product is the result of both national and international research efforts. Hence, we are dealing with a joint product. It would be very difficult to say which partner provided which proportion of the product in any general sense. It would also be divisive to try to do so. A partnership is involved and it is one in which the national role will become more important as national systems are strengthened.

Virtually all of this work is in the public sector; the only DC case where the private sector has been active is for wheat in Argentina, and

even there extensive use has been made of CIMMYT germplasm.

Sources of Data on HYVs

Except for a few countries in Asia, national data on HYV use are seldom found in the usual published series of agricultural statistics. They exist, if at all, in the byways. One often needs to be a detective to track them down. The search is neither swift nor sure. I have, however, been involved in this process, off and on, since 1969.

The range and apparent quality of data available is quite wide - from rather complete national statistics in Asia to fragmentary estimates for most African nations. Fortunately there is a fairly close correlation between extent of HYV use and the quality of the statistics, except for China.

Where official data exist, they are usually reported in terms of (1) total HYV area, or (2) area of individual varieties. In the former case, typified by India, the definition of HYVs is not stated; in the latter case, typified by Burma, I attempt to sort out the HYVs. Where official estimates are not available, it has been necessary to rely on estimates from plant breeders and others.

Sufficient data are available for a number of Asian nations to construct a full time series from the mid 1960s to the early 1980s. In some cases, time series data have been found only for a few years. In many others, only estimates for occasional years have been noted.

Obviously there are many weaknesses in these data - especially with respect to definition, coverage and consistency - but it is not possible to explore these problems here.

Estimated HYV Area

The data may be arranged and briefly examined in two ways: (1) cross sectional, and (2) time series.

Cross Sectional Data. These are built up from all countries covered for the 1982-83 crop year. They are summarized for major regions in Table 1. The HYV area in the first four regions was slightly larger for wheat than for rice. If communist Asia (for which the data are particularly uncertain) is included, the situation changes substantially and the HYV rice area becomes much larger.

The area of HYVs of both crops in the four regions is heavily concentrated in non-communist Asia (76.2%), followed at a considerable distance by Latin America (13.3%) and the Near East (9.5%), trailed by Africa (0.9%). Substantial HYV wheat areas are located in Latin America and the Near East. An extensive area of HYV rice is found in Latin America.

Similar patterns are found when the HYV area is expressed as a proportion of the total area devoted to that crop in a region. Excluding communist Asia, the overall proportion was somewhat higher for wheat (60.9%) than for rice (41.6%). Again the situation is reversed if communist Asia is included. Either way, the combined HYV figure for both crops was about 50%.

With the exception of communist Asia, the HYV proportions are higher for wheat than rice in each region. Surprisingly high proportions are found for HYV wheat in Latin America and Africa. Low proportions are found for HYV rice in the Near East and Africa.

Table 1. Estimated Area Planted to High-Yielding Varieties of Wheat and Rice in the Major Regions of the Developing Countries, 1982-83

Region	Wheat	Rice	Total
<hr/>			
HYV Area	-million hectares-		
Asia <u>1/</u>	25.4	36.4	61.8
Near East <u>2/</u>	7.6	0.1	7.7
Africa <u>2/</u>	0.5	0.2	0.7
Latin America	8.3	2.5	10.8
Subtotal	41.8	39.2	81.1
Communist Asia <u>3/</u>	5.1	33.4	38.5
Total	46.9	72.6	119.5
HYV Proportion	- percent -		
Asia <u>1/</u>	79.2	44.9	54.6
Near East <u>2/</u>	30.6	8.4	29.6
Africa <u>2/</u>	50.6	4.7	13.3
Latin America	77.6	32.9	59.0
Subtotal	60.9	41.6	49.8
Communist Asia <u>3/</u>	17.6	81.0	54.8
Total	48.0	53.6	51.3

1/ Includes countries listed in Table 2, plus South Korea and Malaysia.
Excludes Taiwan.

2/ North Africa included in Near East.

3/ China in the case of wheat (semi-dwarf only); China, Kampuchea, Laos, and Vietnam in the case of rice. Excludes North Korea.

The area occupied by HYVs, reflecting to a large extent the distribution of overall crop area (and population), is heavily concentrated in a few countries. The leading six for each crop in terms of area, excluding China, were as follows (percent of total DC HYV area in parentheses):

- Wheat: India (43.2), Argentina (15.6), Pakistan (15.2), Turkey (8.0), Mexico (1.9), and Brazil (1.9).
- Rice: India (47.5), Indonesia (14.9), Philippines (7.0), Bangladesh (6.7), Burma (6.4), and Vietnam (4.8).

The top six represented 85.8% of the HYV wheat area and 87.3% of the HYV rice area. The remaining proportion of the HYV area is made up of a large number of countries, especially in the case of HYV rice in Latin America and Africa.

Time Series Data. Two series are available for the period since the mid-1960s. One, reported here in Table 2, and Figure 1 is for selected Asian nations. The trend for both HYV wheat and rice has been rather steadily up, although there have been some plateaus. The rate of increase for HYV rice was greater than for HYV wheat. The HYV rice area dropped slightly in 1982-83 but, based on data from India and Indonesia, may have increased substantially in 1983-84.

The data may also be expressed in terms of proportion of total area planted to HYVs (Figure 2). The proportion of area planted to HYV wheat was considerably higher than for HYV rice (80% for wheat and 45% for rice in 1982-83). Both have expanded, but the proportion planted to wheat grew more sharply at first and then slowed; rice has increased more slowly and more steadily. A tapering off of the rate of growth of HYV wheat

Table 2. Estimated Area Planted to High-Yielding Varieties of Wheat and Rice, South and Southeast Asian Nations, 1965-66 to 1982-83.

Crop year	Wheat <u>1/</u>	Rice <u>2/</u>	Total
- hectares -			
1965-66	12,300	13,800	26,100
1966-67	653,500	984,500	1,638,000
1967-68	3,928,000	2,584,000	6,512,000
1968-69	7,243,500	5,198,400	12,441,900
1969-70	7,677,200	7,487,300	15,164,500
1970-71	9,720,000	9,631,300	19,351,300
1971-72	11,278,100	12,953,300	24,231,400
1972-73	13,744,300	14,753,300	28,497,600
1973-74	14,726,500	18,895,600	33,633,100
1974-75	15,196,400	20,290,400	35,486,800
1975-76	17,795,000	22,374,100	40,169,100
1976-77	19,491,400	24,031,600	43,523,000
1977-78	20,931,800	28,124,400	49,056,200
1978-79	21,534,600	30,216,400	51,750,700
1979-80	21,339,000	30,261,400	51,600,400
1980-81	22,781,200	33,909,500	56,690,400
1981-82	23,778,400	36,025,300	59,803,700
1982-83	25,341,200	35,725,400	61,066,600

1/ Bangladesh, India, Nepal, and Pakistan

2/ Bangladesh, Burma, Indonesia, Korea, Nepal, Pakistan, Philippines, Sri Lanka, and Thailand.

Figure 1

Estimated Area Planted to High-Yielding Varieties of Wheat and Rice, South and Southeast Asian Nations, 1965-66 to 1982-83

Million Hectares

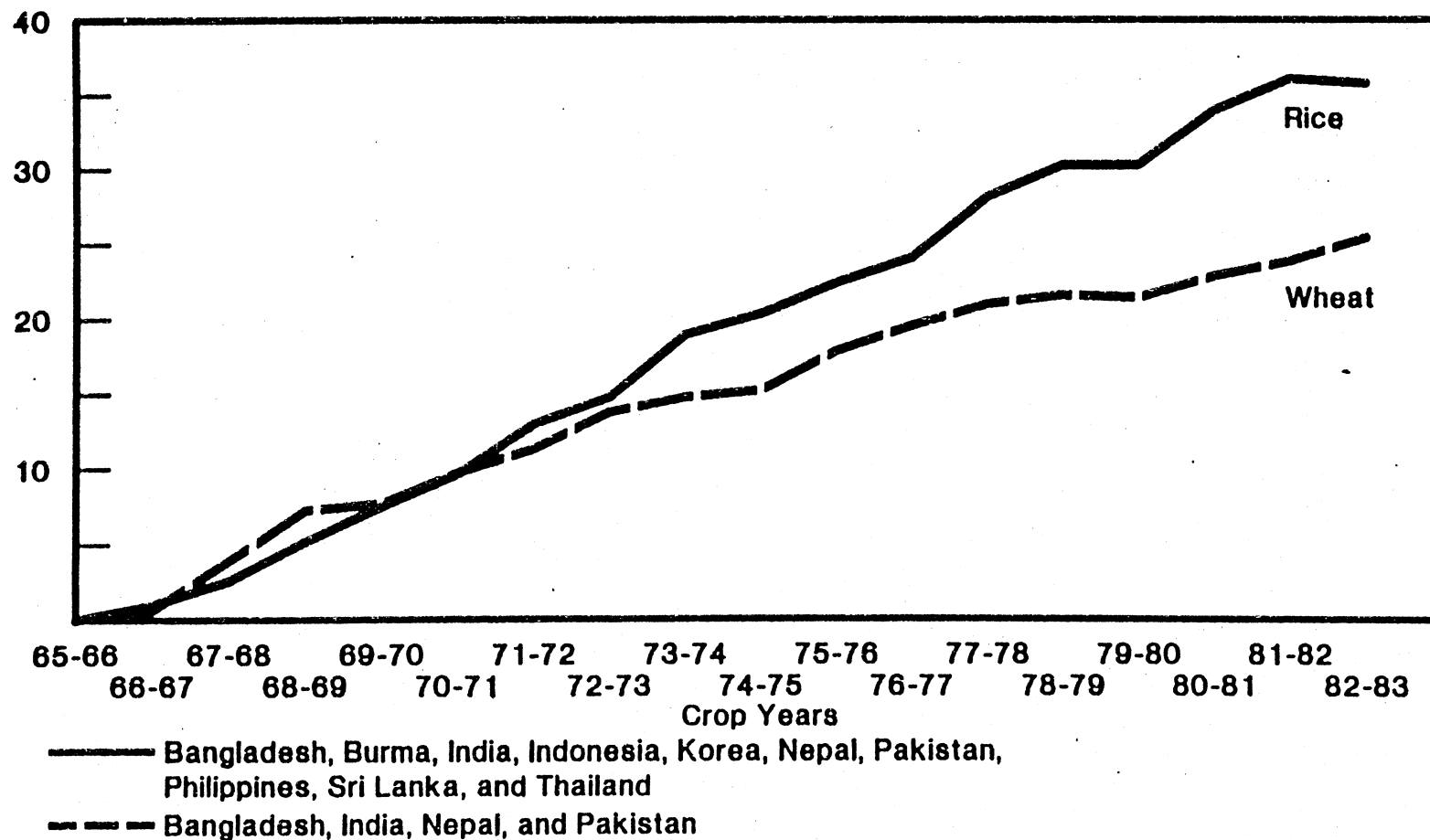
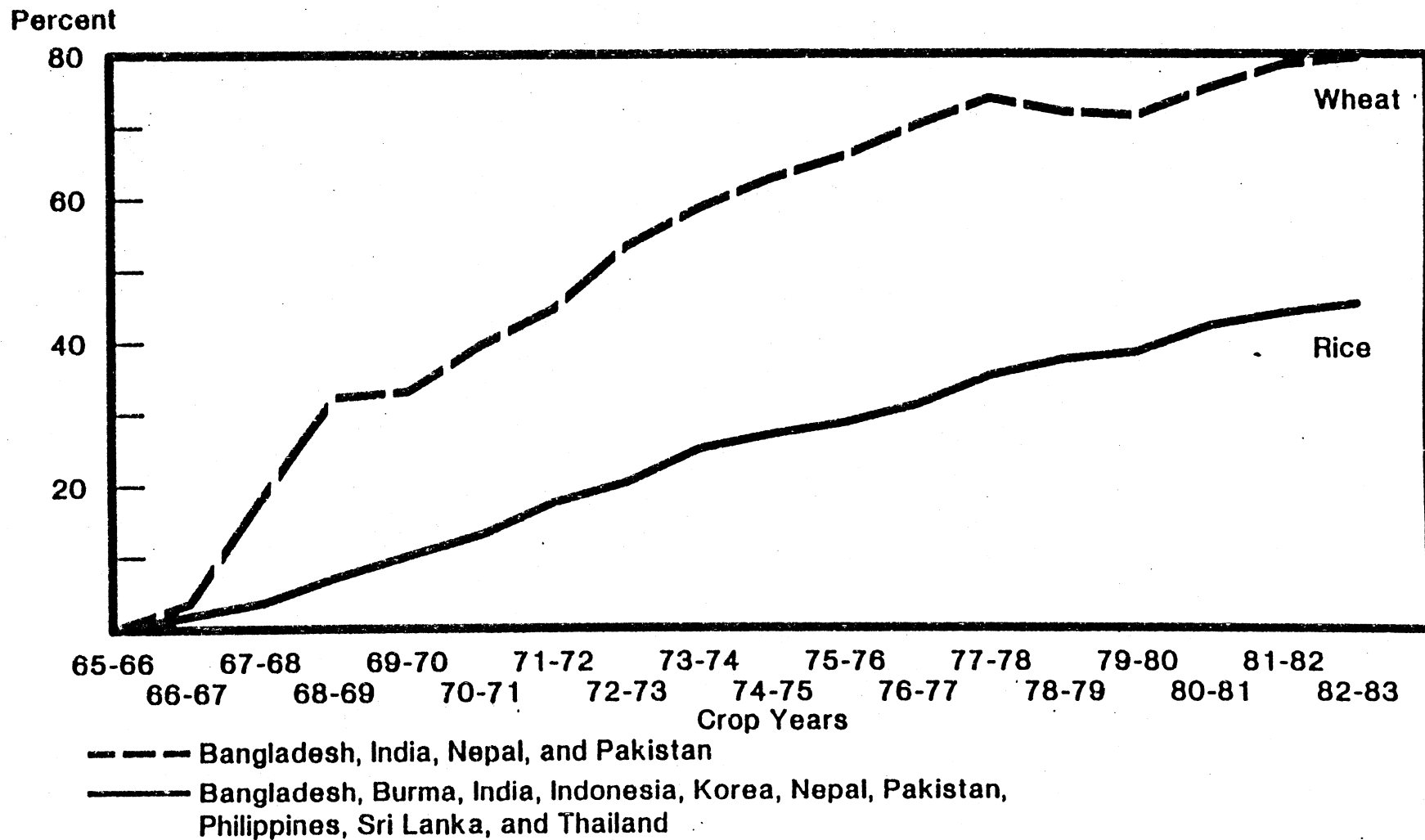


Figure 2

Estimated Proportion of Area Planted to High-Yielding Varieties of Wheat and Rice, South and Southeast Asian Nations, 1965-66 to 1982-83



area is to be expected under these circumstances. The future pattern for HYV rice is uncertain. Several supply and demand factors will keep the HYV adoption rate at less than 100%.

Additional time series have been constructed by others (not shown). CIAT gathers estimates of area planted to HYV rice in Latin America every three years or so. E. M. de Rubinstein has fitted these point data for each country by a free-hand curve and has added the resulting data to produce a regional total. As part of the CGIAR Impact Study, Herdt and Rustagi have statistically fitted my point data for wheat and rice in other regions to produce country and regional estimates. These techniques appear reasonable, but I am aware of the weaknesses of the basic data.

The data, while certainly imperfect, clearly show that the HYVs have firmly established themselves over a wide area in the DCs during a relatively short period of time. Further details will be provided in two publications, one for each commodity, to be issued by AID this fall. (It may be of interest to note that semi-dwarf varieties are also now widely used in the United States. In 1984 they occupied nearly 60% of the wheat area and over 20% of the rice area.)

Nature of Effects

It has not been my intent here to try to estimate the effect of the HYVs on production in quantitative terms. Still, it may be useful to provide some comments on the general nature of these effects, for there are more than may immediately meet the eye.

Direct Effects. Both grain and straw are involved. Effects on grain may be both quantitative and qualitative. In quantitative terms, yields are nearly always increased, resulting in increased returns to some

producers and lower prices to all consumers (a matter of particular importance to the poor). But several factors beyond the variety itself are involved in increasing yields: 'water and fertilizer are the principal ones. In practice, it is difficult to sort out the specific effects of each: a high degree of intercorrelation is involved. Qualitative effects involving consumer acceptance and nutritional quality must also be considered. Both quantitative and qualitative aspects interact to influence nutritional levels of consumers. While the HYVs increase grain yield, they may - because of their shorter height - reduce straw yields, which may not be desired where it has a high value as livestock feed or for other uses.

Indirect Effects. These principally derive from the earlier maturity, and hence shorter growing season, of most HYVs. This characteristic facilitates - where practiced - more intensive multiple cropping patterns. An additional crop of the HYV or some other plant may be raised during the year. Wheat, for example, has become an important winter crop, between rice crops, in Bangladesh. This effect could be viewed as an increase in area or yield, or both (when measured on a yearly basis). It is more complex to measure and is seldom evaluated in quantitative terms. Yet it may be as important, in many cases, as the direct yield effect.

Other Effects. These are variable and may include effects on: relative profitability of other crops, demand for inputs including labor, equity issues related to by-passed farmers or regions, etc. Measurement of these and other effects can get quite complicated.

Remaining Research Challenges

While much has been accomplished, much remains to be done. On one

hand, the accomplishments to date must be consolidated and maintained. And on the other, they need to be extended to additional areas.

The first task is largely one of maintenance research. Crop varieties are "perishable": new types of insects and disease and other problems constantly emerge, normally rendering varieties obsolete in an all-too-short period of time. They must constantly be replaced. Other threats must be countered. One emerging problem is that some of the newer rice varieties have derived their improved characteristics at the cost of lodging resistance; a new cycle of breeding for short height may be needed. In the future, we will likely have to run harder to stay even.

The other major task concerns by-passed regions. Most of the HYVs have so far been used in areas with irrigation or relatively favorable rainfall. The task now is to develop improved rice varieties for upland areas and wheat varieties which can be grown under a wider range of temperature conditions. Because of the environmental constraints, high yields may not be obtainable, but increased yields are possible.

A related question concerns future yield increases. Once the HYVs have been widely adopted, and fine tuning completed on related matters, where are major yield increases to come from? In the case of rice no variety yet exceeds the yield potential of IR8, introduced nearly 20 years ago. The yields of hybrids are definitely higher but seed cost and distribution represent real problems. In a number of areas, biotechnology holds significant promise, but its impact could be lessened by inadequate infrastructure in developing countries.

But more is involved than technologies: government policies have been important in the past and may be even more so in the future.

Thus we continue to face a range of research problems on wheat and rice which will provide considerable challenge to the international agricultural research system for the foreseeable future.

Future Investment in Research

How much is it appropriate for the CGIAR and national research systems (NARS) to spend on wheat and rice research? Resources are limited and there are many demands for increased research on other commodities and in other areas.

The CGIAR has devoted a substantial portion of its research resources to these two crops. The exact figures vary depending on the category: one recent tabulation of core and special project funding in 1983 indicated 25.4% for rice and 10.0% for wheat and barley. Another tabulation for core projects in 1985 produced figures of 23.3% and 12.6%, respectively.

As a consequence of a comprehensive study of strategic issues and priorities, the Technical Advisory Committee (TAC) of the CGIAR is considering recommending that the proportion spent on both crops - but especially rice - should be reduced over the next 15 years if system resources remain constant in real terms. If resources increase, then wheat might be raised but rice would remain at the lower level just noted. The principal reason given for these recommendations is that some of the key NARS are now strong enough to take on some of the applied research functions previously performed by the IARCs.

The actual and potential strength of the NARS is a matter of some uncertainty. Clearly, however, they are a critical variable. Some data compiled by Evenson a few years ago suggest that in 1980 about 95% of all

the funding for agricultural research in the DCs was provided through the NARS and about 5% through the CGIAR. Evenson has more recently estimated that from 1972 to 1979 the CGIAR provided about 4% of the total funding for wheat research and 7% for rice. If these figures still hold, we face the question of how much the IARC proportions can be reduced if they are to continue to provide the essential research, service, and training support needed by the NARS.

Any suggestion to significantly reduce IARC funding for research on these two key crops is - in part for reasons noted in the previous section - bound to be controversial. It is not clear how the CGIAR will react to it. But the proposal clearly does raise some important questions of resource allocation which cannot be easily answered and which require further study.

Concluding Remarks

The HYVs (or MVs) of wheat and rice are a vivid example of the impact of public international agricultural research at the farm level in developing nations. In the course of less than 20 years, HYVs have expanded to cover about half of the area devoted to these crops. This level of accomplishment, while impressive, cannot be taken for granted. Research must continue to maintain the gains to date and to extend their benefits to other areas. Neither will be easy. A major question which remains is how much to spend on research for these two commodities compared to potential investment in other commodities and other areas of research. There is much for the agricultural economist to do in documenting the effects of research and in developing the needed data and analyses to guide resource allocation in the future.

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