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THE GREEN REVOLUTION: PAST AND PROSPECTS

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PREFACE

The first draft of this manuscript was prepared in the U.S. Department of Agriculture (USDA) and was intended to serve as a source paper for a comprehensive review of the world food situation which is being prepared by the Economic Research Service. The review is to be published prior to the World Food Conference. This manuscript was not intented to be reproduced as such but was to serve as one of many sources for the authors-editors of the ERS report.

Because of the current interest in the status of, and prospects for, the green revolution, I decided to revise the paper and have some copies run off for limited distribution. This was done as part of my activities with the Agency for International Development (AID). The paper is still by no means finished and should be considered a working draft. Review comments would be appreciated. Those providing helpful comments to date include Glenn Anderson, Jay Atkinson, Guy Baird, Daniel Bromley, William Jones, Richard Reidinger, and Don Winkelmann.

Related reports which I have prepared include:

- Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations, Economic Research Service, U.S. Department of Agriculture (in cooperation with U.S. Agency for International Development), Foreign Agricultural Economic Report No. 95, June 1974, 77 pp.

- (with William Jones) "Evaluating the Green Revolution", presented at the joint meeting of the American Association of Science and the Consejo National de Ciencia y Technologia, Mexico City, June 1973, 86 pp. (Briefly summarized in Science and Public Affairs, October 1973, pp. 50-51.)

The bulletin provides historical and statistical data. The talk evaluates the benefits of the green revolution from several points of view; it also includes an evaluation of the green revolution in Mexico.

This paper builds to some extent on each report, but to a much greater extent attempts to evaluate prospects for the future. The latter is done primarily in terms of the major inputs affecting the supply side.

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I. INTRODUCTION

What happened to the "green revolution"? A few years it was being touted by some as providing the world breathing space from food problems for several decades. Recently others have spoken of the demise of the "green revolution". The reports of both its promise or death are greatly exaggerated. The purpose of this paper is to try to give a more balanced view of the "green revolution"--its past and its prospects.

To do so, however, we first need to define ther term somewhat more precisely and to delineate its historical and geographic dimensions.

A. Defining The "Green Revolution"

Although the "green revolution" is by now relatively well known, the term has a number of severe limitations. It is imprecise, misleading, and emotive. The loaded phrasing in particular leads to excesses in popular use--to over selling and to over-buying. Still, we seem to be stuck with it.

"Green revolution", as used here, will refer to the adoption of both (1) high-yielding varieties (HYV's) of grain - especially wheat and rice - and (2) an associated package of inputs, in certain less developed nations. The varieties usually have short stiff stalks (that is they are semi-dwarf or dwarf), are highly fertilizer responsive, and are relatively photoperiod insensitive (which means that they are fairly flexible as to planting date and may mature earlier). They are continually being improved through breeding, particularly to incorporate factors which will lead to yield stability. The package of inputs always includes farm chemicals and improved management, and usually includes insecticides, pesticides, and water control.

Hence we are not speaking of one single technique or event but rather a package of techniques which are continually being modified. In short, we have a complex and dynamic technology.

B. Historical and Geographic Dimensions

The current "green revolution" originated in Mexico in the mid-1940's. The first improved varieties were released in 1948 and were followed by a constant stream of new varieties. Adoption was rapid; within 5 years, different new releases had taken over 50% of Mexico's wheat land; within 12 years, 90%. Thereafter, the HYV area leveled off, but as total wheat area declined, it increased in proportion. 1/

Outside of Mexico, HYV's of wheat and rice began their take-off in the mid-1960's. The timing was fortunate because this was a period of severe drought in South Asia and world food supplies had sunk to low levels. The rate of adoption through 1972/73, as indicated in Figure 1, has been rapid.

As of 1972/73, in Asia and North Africa, the HYV wheat area totaled about 41.6 million acres (16.8 million hectares) while the rice area was approximately 38.7 million acres (15.7 million hectares). In addition, nearly 1.1 million acres (0.43 million hectares) of HYV rice were planted in Latin America. Data for individual LDC's are provided in Table 1. Substantial quantities of HYV rice are also found in Cuba and North Vietnam.

While by 1972/73 the HYV area in the non-Communist Asian developing nations was assuming significant proportions (roughly, 35% of the wheat area and 20% of the rice area), the HYV area in other areas of the world (aside from Mexico) was still relatively small. To be more specific:

Figure 1. ESTIMATED HIGH-YIELDING WHEAT AND RICE AREA, ASIA AND NORTH AFRICA, 1965/66 to 1972/73
(Excluding Communist Nations)

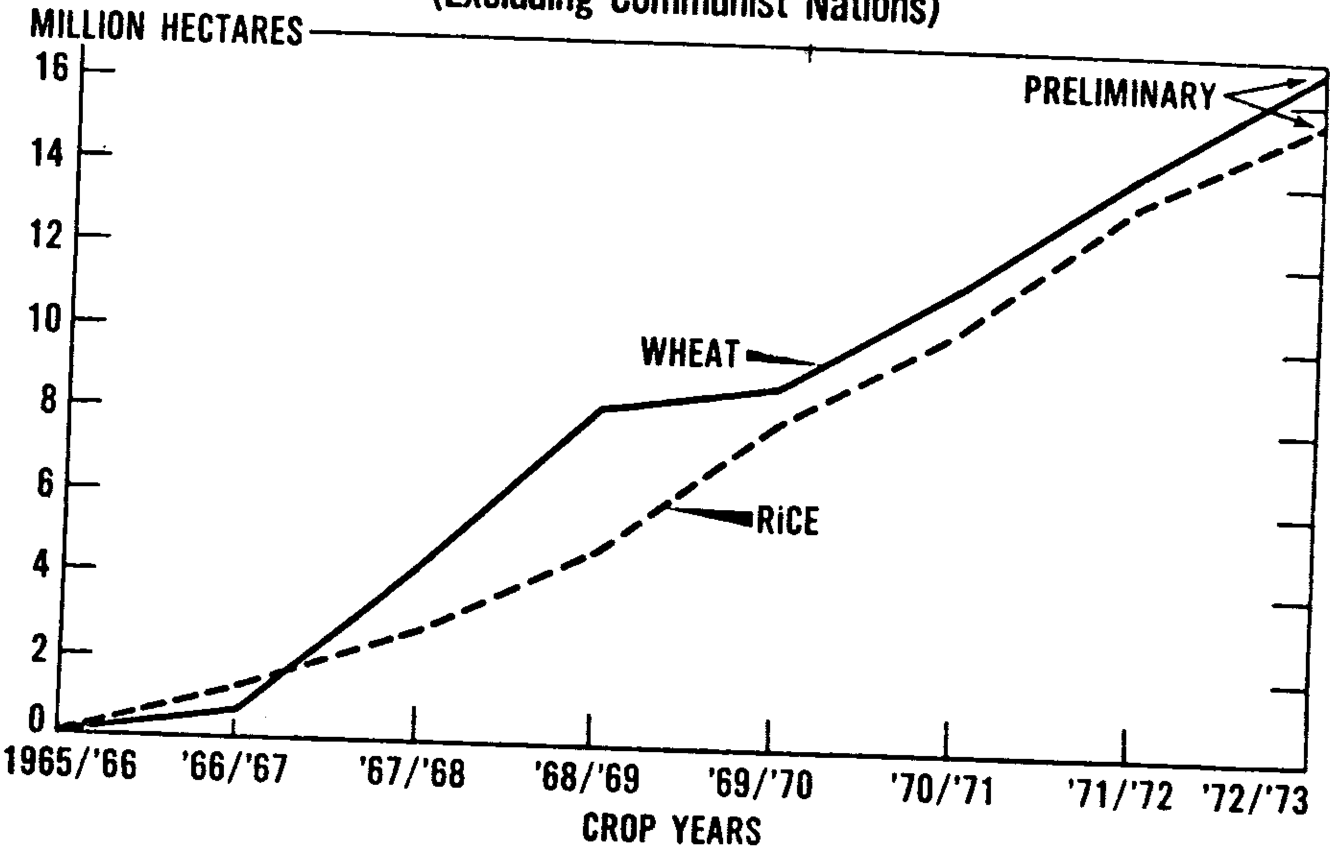


Table 1. ESTIMATED AREA PLANTED TO HIGH-YIELDING VARIETIES OF WHEAT AND RICE, LESS DEVELOPED NATIONS, 1972/73 1/

	Hectares	Acres
WHEAT		
Asia		
India	10,236,800	25,295,200
Pakistan	3,338,800	8,250,000
Turkey 2/	650,000	1,606,200
Iraq	457,000	1,129,000
Afghanistan	450,000	1,112,000
Iran	298,000	736,400
Syria	180,000	444,800
Nepal	170,300	420,700
Bangladesh	21,450	53,000
Lebanon	20,000	49,400
Jordan	150	380
Subtotal	15,822,500	39,097,400
Africa		
Algeria	600,000	1,482,600
Morocco	294,000	726,500
Tunisia	99,000	244,600
Subtotal	993,000	2,453,700
Total	16,815,500	41,551,100
RICE		
Asia		
India	8,639,100	21,347,200
Philippines 3/	1,752,000	4,329,200
Indonesia	1,521,000	3,758,000
Bangladesh	1,069,600	2,643,000
Vietnam (South)	835,000	2,063,300
Pakistan	643,500	1,590,000
Thailand	350,000	865,000
Malaysia	217,300	537,000
Burma	199,200	492,200
Korea (South)	187,000	462,000
Nepal	177,300	438,000
Laos	50,000	123,600
Sri Lanka	17,600	43,500
Subtotal	15,658,600	38,692,000
Latin America		
Subtotal	429,600	1,061,400
Total	16,088,200	39,753,400

1/ Excludes Communist nations. Also excludes HYV wheat in Mexico and Guatemala and HYV rice in Taiwan.
2/ 1971/72 estimate.
3/ Unofficial estimate.

- The "green revolution" through 1972/1973, as may be seen in Table 1, was highly concentrated in Asia – in south and west Asia for wheat, and south and east Asia for rice. Relatively small quantities of HYV's were raised elsewhere, as follows: wheat, north Africa; rice, Latin America. (In addition, HYV rice varieties are also raised in North Vietnam and Cuba). Hence much of the less developed world is not included.
- Within Asia, the HYV area was very heavily concentrated in a few countries. India and West Pakistan together accounted for nearly 81% of the total HYV wheat area. The rice area was not concentrated to quite the same degree: four countries (India, the Philippines, Indonesia, and Bangladesh) accounted about 83% of the total. India alone represented 61% of the wheat area and 55% of the rice area.
- The HYV's represented significant portions (25% or over) of total crop area in only a few countries in 1972/73:
  - Wheat. Nepal, Pakistan, India, and Algeria.
  - Rice. Philippines, Pakistan, Malaysia, Vietnam.

The highest figure was 66%.

Within these countries, the regional distribution of the HYV's is often far from even. In 1972/73 in India, for instance, 48% of the HYV wheats and 40% of the HYV rice varieties were each concentrated in two states (each different, however). The concentration was even more pronounced in Pakistan: 74% of the HYV wheat was located in one province (state) and 77% of the rice in another province. While points of concentration in South Asia parallel overall wheat or rice production to some extent, they also tied to the availability of irrigation.

Thus, while the "green revolution" in wheat and rice has spread remarkably in a few years, it is still quite heavily concentrated in a relatively few countries or in certain regions of these countries. There it is of major and undeniable importance. But all of this should not be allowed to cloud the fact that there are many regions of the developing world which have not yet been significantly touched by the "green revolution".

C. Organization of the Report

This report is organized into three main text sections. The first tries to place the "green revolution" in analytical prespective by viewing it in terms of the usual life cycle of an agricultural technology. The second section discusses some of the ways of measuring the effect of the "green revolution" on agricultural output in historical terms; special emphasis is placed on yields. The third section turns to prospect in terms of possible changes in the supply of individual components in the input package. A final chapter summarizes some of the key interrelationships between inputs and suggests some of the related difficulties for evaluating prospects for the "green revolution". Little is said about the social impacts of the "green revolution": these have been discussed in part in a previous paper and by numerous other writers. 2/

II. LIFE CYCLES OF AGRICULTURAL TECHNOLOGY

Most, if not all, agricultural technologies have to embody certain common features if they are to be adopted. And if adopted, they follow a fairly predictable life cycle. The "green revolution" shares these general characteristics.

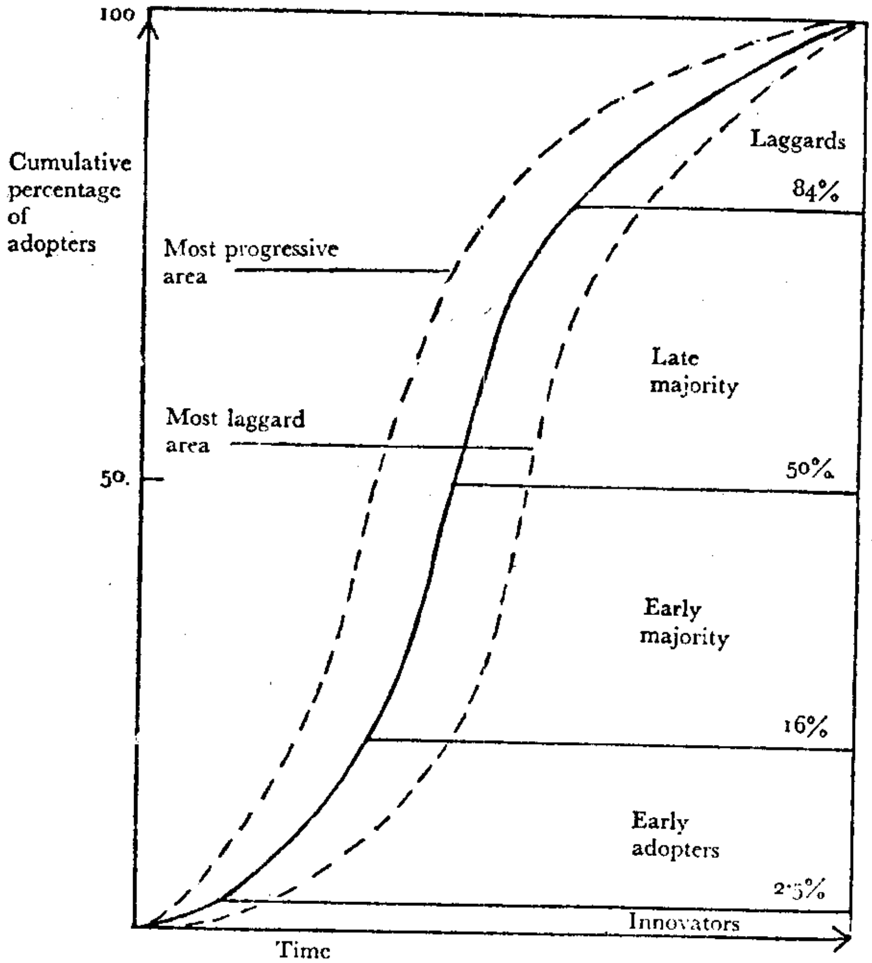
A. The General Pattern 3/

To be adopted initially, a technology usually has to increase profits. It usually does this by lowering production costs per unit. Under free market conditions, cost-reducing innovations normally result in expanded output. Few technologies increase the price received except as they bring about an improvement in product quality (this is not so far the case for the "green revolution").

The usual adoption process for a technology follows the well known S-shaped curve (Figure 1). At first it is picked up by a few operators, then the rate of adoption increases, and finally tapers off as the technology becomes fully adopted or is adopted as far as existing circumstances permit. Progressive regions may well go through the process more quickly than poorer regions. This pattern is reflected in the adoption pattern for hybrid corn in the United States (Figure 2).

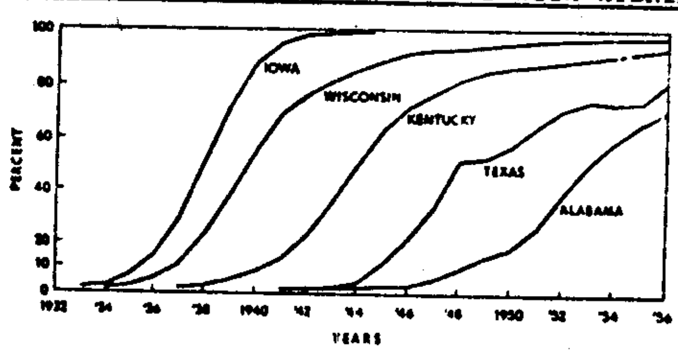
The first adopters, in return for the risk they take, usually are the ones to reap the greatest returns. As more and more farmers take up the practice and output expands, prices are lowered (the rate of reduction depending on the elasticity of demand for the product). The final group of farmers to take up the practice may not find added profit but may have to adopt it just to keep their costs in line with other farmers.

Figure 2. THE S-SHAPED ADOPTION CURVE



Source: Barbara Harriss, "Innovation Adoption in Indian Agriculture - the High Yielding Varieties Programme", Modern Asian Studies, January 1972, p. 74.

Figure 3. PROPORTION OF CORN ACREAGE PLANTED WITH HYBRID SEED



Source: Zvi Griliches, "Hybrid Corn: An Exploration in the Economics of Technological Change," Econometrica, October 1957, p. 502.

The process is thus clearly not equitable to producers; not everyone who adopts the practice gets the same return. Some do well, others don't. Even worse, those who profit the most are often better off to start with - they have the income to afford the risk, and the knowledge to see its potentials or how to realize them. The last adopter is usually in the reverse position. Thus income disparities among producers may be widened.

On the other hand, consumers are generally winners. They are provided added supplies at lower relative prices. In this way their incomes are augmented and their variety of selection enhanced. Though they benefit the most from production-augmenting technology, they are usually the last to appreciate it.

How closely has the "green revolution" followed this general adoption pattern? Since the "green revolution" is composed of a package of divisible technologies, it may be useful to break our discussion down into two categories: (1) adoption of the seeds themselves, and (2) adoption of associated practices.

B. The High-Yielding Seeds

The data presented on the annual increase in area planted to the HYV's in the first section of this paper suggest a very rapid overall rate of adoption in certain Asian nations. In some of the most advanced areas, such as Pakistan's Punjab, farmers were more rapid in adoption of the new wheat seed and less conservative in using it than were Iowa farmers in adoption of hybird corn in the 1930's and 1940's. 4/

Estimates of the rate of adoption at the national level for wheat and rice in the leading using nations are presented in graphic form in Figures 4 and 5. Few of the countries have, at the national level, followed the S-shaped curve in its traditional form: the example of wheat in Pakistan and India and rice in the Philippines would seem to be as close as any. The others differ from the classical form in that after the first year the rate of adoption was more of a linear nature. For most of the countries, however, the level of adoption still appears to be on the increase - though the current fertilizer shortage (about which we will say more later) may put an upper lid on sooner than have might otherwise been the case. Rates of adoption within nations may, as suggested, vary sharply by region.

No country cited here has reached a 100% level of adoption. Few are likely to. Evanson suggests that "In many cases it appears that less than 50% of the wheat and rice area is likely to be planted to the high-yielding varieties". 5/ Several groups on factors constrain complete adoption. On the supply side there are about three major groups:

(1) Institutional/Economic. Includes such factors as farm size, credit availability and tenure status.

(2) Uncertainty/Risk. Relates to both economic and agronomic risks.

(3) Physical/Environmental. The main components are water control and temperature. Agro-climatic factors may simply not favor HYV adoption in some production areas.

Figure 4. Proportion of Wheat Area Planted to High Yielding Varieties

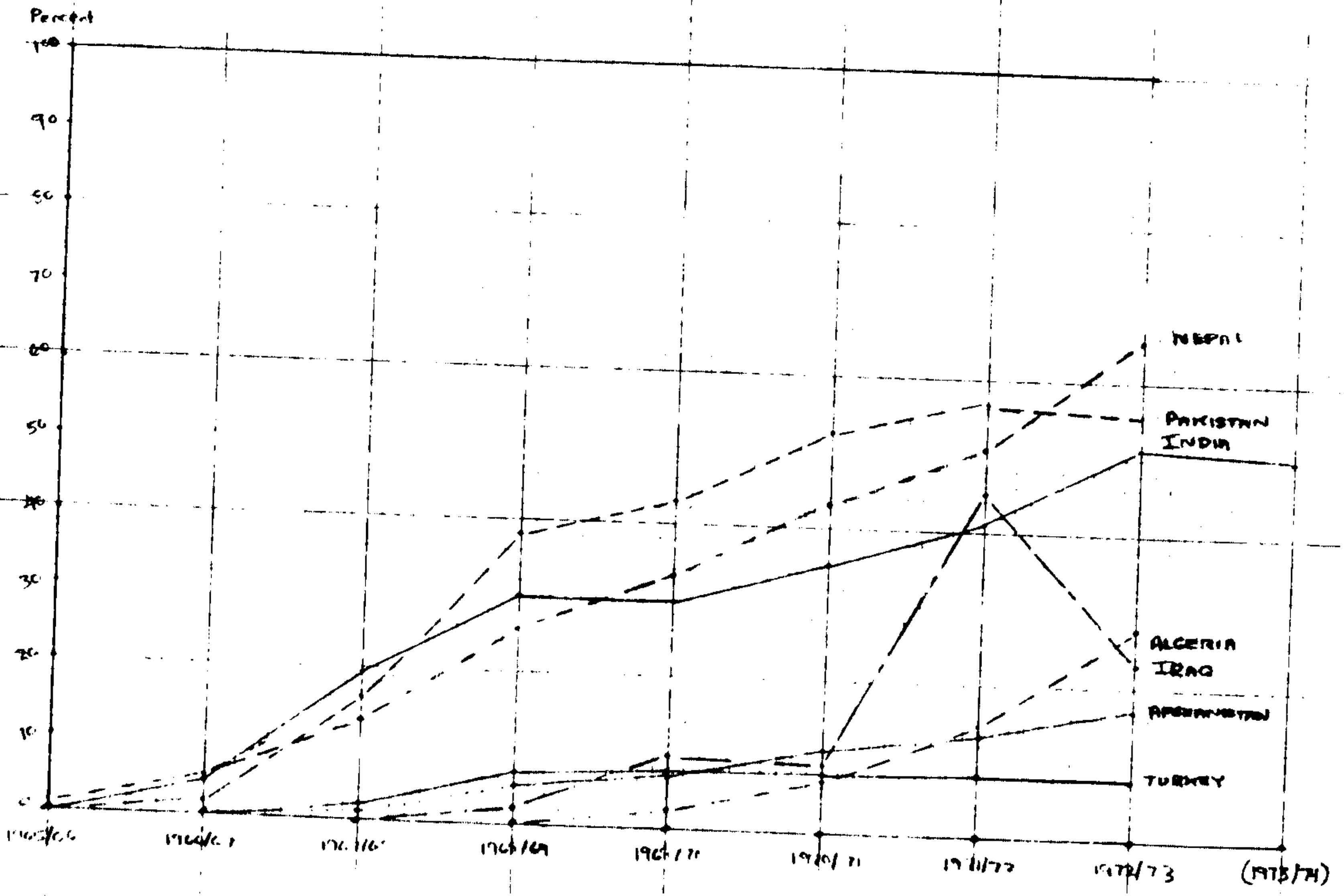
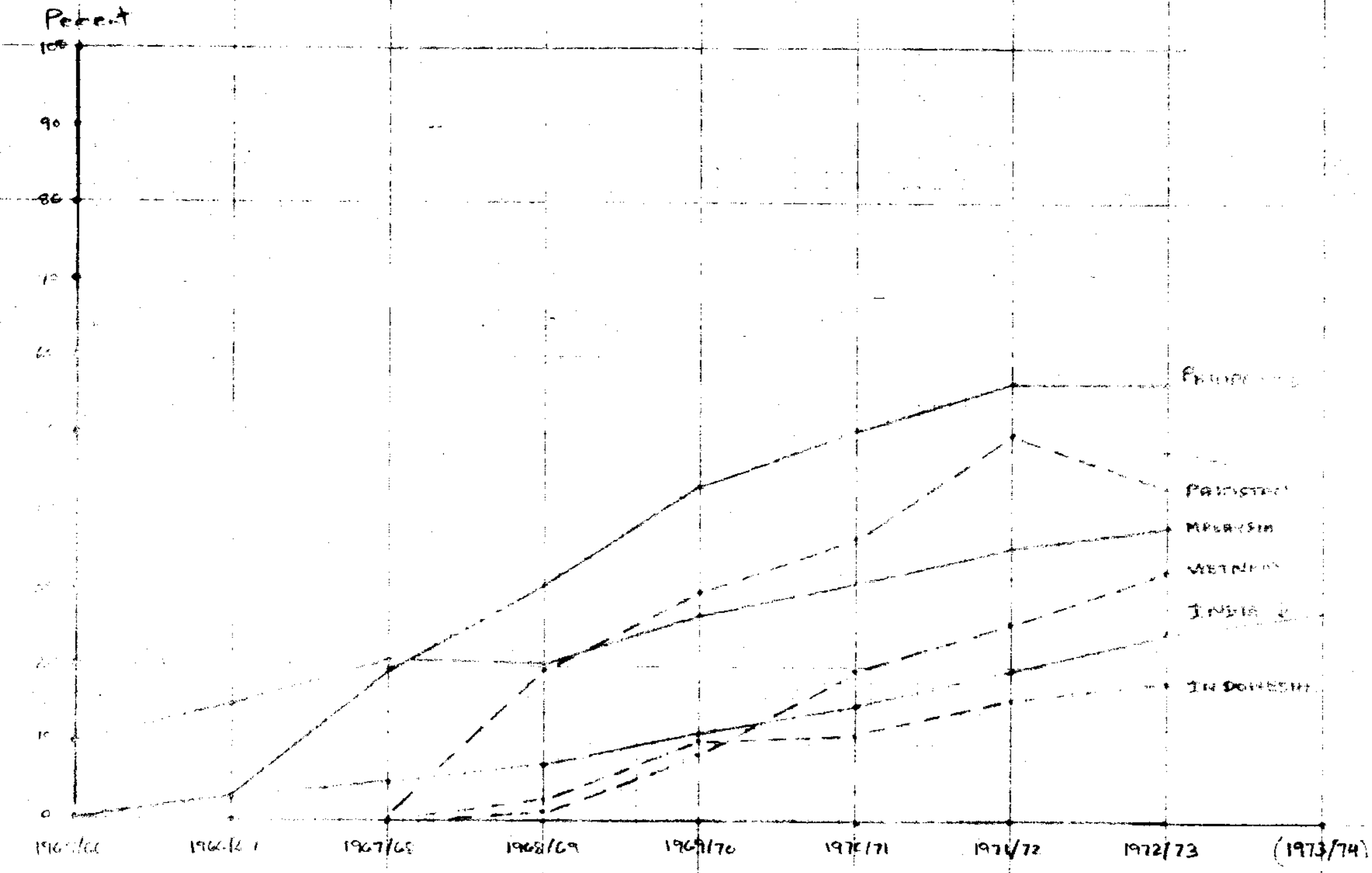


Figure 5. PROPORTION OF RICE AREA PLANTED TO HIGH YIELDING VARIETIES



These factors will not be discussed in detail here; most will emerge later, particularly in Chapter IV. Suffice it to say that many of the smaller farmers in the LDC's, because of their weak resource base, are risk minimizers rather than profit maximizers. 6/

On the demand side, it must be recognized that the current HYV's do not fully meet consumer requirements in some areas. In many areas, for example, there are long-established tastes for certain types and kinds of grains which are not satisfied by the present HYV's. Breeding programs at the national level have, however, increasingly accounted for local taste preferences and this problem is not nearly as important as it was 5 years ago.

In addition to these supply and demand factors, the HYV's are unlikely to completely replace traditional varieties in most major areas in the near future because of incomplete adoption of other inputs.

C. Associated Inputs

The HYV seeds are only one component of the green revolution. The other major ingredients are (1) improved water control, (2) increased use of farm chemicals for fertilization and plant protection, and (3) improved management practices such as seedbed preparation, seeding rates, weed control, and timing of fertilizer applications. These are, except in some cases for water, usually highly divisible inputs. Many farmers, even if they fully adopt the HYV's, fail to adopt all of the recommended package of inputs or practices. In India, for example, by 1969 only 12% of the HYV farmers were fully following recommendations. 7/

We might think of an S-shaped adoption curve for each of these practices, which falls under the adoption curve for the seeds. This is illustrated in Figure 6. 8/ Input X might be thought of as fertilizer, Y as pesticides, and Z as improved cultivation practices. (Irrigation doesn't fit this pattern quite so readily; water is not something that is available to each farmer in highly divisible quantities - but where it is provided by tubewells, for instance, a similar pattern might appear.) 9/ The relative level of use at any given time is given by a vertical line (as at a) intersecting each curve. The exact pattern for each country or region might vary widely. It may also vary by farm: in terms of the above percentage, it is not the same 12% who adopt all improved packages. "The search for a survival algorithm results in most participants being progressive in some aspects but not in others". 10/

Many of the same factors which retard the adoption of the seeds also retard the adoption of the associated inputs (in this respect we also have a "package" of common retarding factors). The main difference is that some of these other inputs have a much higher price tag to them. Fertilizer is a particularly significant cost factor. Hence many farmers have settled for a modified input package - one with a rather low investment in fertilizer. It provides some jump in yields but does not expose them to sharp risk. In some cases, however, these lower than recommended levels of use may represent an economic optimum: the recommended levels are, for a variety of reasons, may not be economic. And in some cases the needed imports may simply not be available in the right form at the right time.

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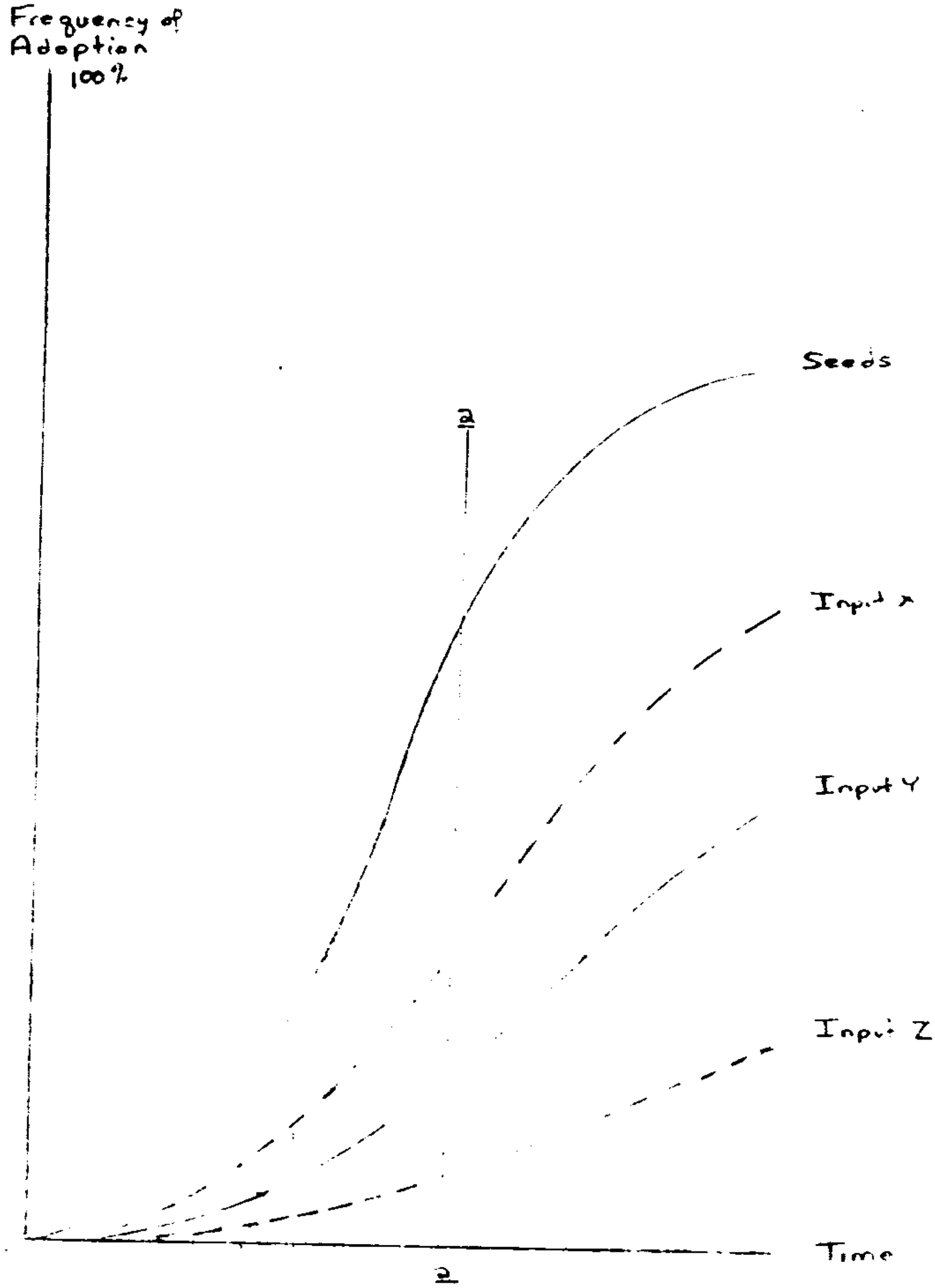
Figure GENERALIZED ADOPTION CURVES FOR AGRICULTURAL INPUTS



Thus we see that the "green revolution" is roughly following the usual course of agricultural technologies. After an initial spurt in adoption, the increase in the rate of adoption will eventually fall off. But instead of thinking of the green revolution as one S-shaped curve, we should think of it as a group of S-shaped curves, one for each of the technological inputs (aside in some cases, from irrigation water). The full package is seldom used at recommended levels.

III. EFFECT ON YIELD PRODUCT: THE HISTORICAL RECORD

Despite the widespread usage of the term "high-yielding varieties" (HYV), there has been relatively little study of average relative yields at the farm level or of the overall impact of the HYV package on wheat or rice production. There is good reason for this. It is difficult enough to gather rather simple area data. Yield or production data which have meaning over a wide area, or which permit close and scientific comparision of the HYV's and traditional varieties, are very difficult to obtain.

The matter will clearly not be settled in this chapter. But a few ideas will be put forward which may give at least a some idea of how the relative significance of the "green revolution" might be approached or weighed. (I plan to do some further work on this subject in the months to come.) Although the emphasis will be on the quantity of production, it is recognized that the "green revolution" may also have qualitative effects on the types of products produced.

A. Types of Effects on Production

It is important to realize that the HYV package has both direct and indirect effects on production.

1. Direct Effect on Output

In assessing the impact of the HYV's, some observers merely look at trends in total wheat or rice production in a particular LDC. This is, if no further steps are taken, a grossly inadequate way of measuring impact because it doesn't take relative changes in area and yield into account. Both are usually involved in the expansion of LDC grain production.

- Area. We have curiously little data about the effect of the HYV's on net cropped area. Considering their biological requirements, however, it is unlikely that they have stimulated the clearing of much new land for their use. Rather, they have probably substituted for existing crops on the better land. The question then is whether they substituted for a traditional variety of a like crop or have substituted for other crops. I assume that they generally substitute for like crops, but this is not always the case, especially on irrigated land.

- Yield. Relatively little analysis has been made of comparative data at the national level. The hooker here is the word comparative: while we have data on yields where HYV's were planted and where traditional varieties are planted, we usually do not have a comparison of the resource base. The HYV's are normally planted on the best land where even a traditional variety might do better.

We shall return to these matters in greater detail in the remainder of this chapter.

2. Indirect Effect on Output

Most discussions of the productive impact of the HYV's have been cast in terms of yields of the specific HYV crop. This may be too narrow a focus.

First, one of the major features of the HYV's is their photoperiod insensitivity which often shortens the time needed to reach maturity and provides greater flexibility in planting dates. 11/ Both help make it possible to grow an extra crop a year in some regions. The multiple cropping index usually rises in "green revolution" areas. Perhaps, in the long run, this effect will be as important or more important than the direct influence on yield. 12/

A second possibility is that the higner yields possible may free resources for other uses. This was recently reported to be the case in Uttar Pradesh in India:

> The comming of the new technology has freed the small farmer from the less profitable cropping patterns on which he could always depend to provide minimum quantities of such staples as wheat and animal fodder for home consumption. If he grows high-yielding varieties, the small farmer can supply his home consumption needs and still have land remaining to grow high-yielding cereals for market or other high-profit crops like sugarcane. 13/

To take these and other effects into account, we should increasingly turn our attention from yields per crop to yields per unit of land per year in Asia. In the remainder of this section, however, we will focus only on the direct effect of the HYV's on wheat or rice production.

B. Relative Importance of Area and Yield

Overall wheat and rice production has clearly expanded in the nations adopting significant quantities of the HYV's. The question is, how much of this expension was due to an increase in yields and how much was related to area expansion?

A rough but simple approach to answering this can be made by comparing changes in area and yield for countries with significant HYV adoption over a given period of time. For our purposes, two averages of four year periods, 1960 to 1963 and 1970 to 1973, have been compared. The comparisons are conservative in that 1972 was generally a poor year. Countries selected were those where 12% or more of the area was planted to HYV's from 1970/71 to 1972/73. Two countries in turn were left out: wheat, Nepal; rice, South Vietnam. 14/

It may be seen from Table 2 that both area and yield expansions were involved in each country. But in every case except Malaysia, the relative increase in yields was greater than for area. The increase in yield ranged from 1.5 times higher than the increase in area for Indian wheat and Indonesian rice, to 2 times for Pakistan wheat, to 3 times for Pakistan and Indian rice. In the Philippines, virtually all of the increase was in yield.

Another rough way to look at the changes would be to weigh the relative importance of area and yield expansion. This can be done in a crude way by adding the area and yield percentages together and then calculating each as proportion of the total. 15/ This rough process suggests that yield accounted for the following proportions of increase in production:

- Wheat. Pakistan 67%, India 60%.
- Rice. Philippines 99%, Pakistan 76%, India 75%, Indonesia 61% Malaysia 27%.

Whether the percentages are precisely correct or not, the point emerges that yield increases have been a significant factor in six of the cases cited, and of moderate importance in the seventh. Yield increases accounted for virtually all of the rice production expansion in the Philippines, and over half in the five other cases.

Area trends in India from 1967/68 to 1973/74 reveal different patterns for wheat and rice. In the case of wheat, there was a fairly significant expansion of both the total area and the HYV area; the overall expansion almost paralled the expansion in HYV area. On the other hand, total rice

Table 2. RELATIVE INCREASES IN PRODUCTION, AREA, AND YIELD, 1960-63 TO 1970-73 AVERAGES, WHEAT AND RICE

	HYV Proportion 1970/71 to 1972/73	Increase in 1970-73 Avg. Over 1960-63 Avg. Production	Area	Yield
	- percent -		--percent -	
WHEAT				
Pakistan	52.3 to 55.9	+77.8	+22.3	+45.2
India	35.5 to 51.5	+115.7	+38.2	+56.1
RICE				
Philippines	50.3 to 56.3	+34.2	+0.4	+33.9
Pakistan	36.6 to 43.4	+132.9	+22.8	+73.3
Malaysia	30.9 to 38.0	+67.2	+43.7	+16.5
India	14.9 to 24.7	+19.3	+4.6	+13.8
Indonesia	11.2 to 18.0 1/	+53.4	+18.8	+29.1

1/ Government programs only. Additional HYV area planted to private plots.

Source: Based on FAS estimates.

area expanded only slightly. This suggests that HYV wheat led to, or further encouraged, a substitution for other crops, while the HYV rice area appears to have largely substituted for traditional varieties. 16/

C. Effect on Yields

Although it is clear that overall yields have gone up in the countries where the HYV's have been extensively adopted, it is difficult to say precisely how much the HYV's themselves contributed to this process. Traditional varieties, given the improved input package, would also respond to some degree. Moreover, the HYV's tend to be planted on the better land. For these reasons, it is almost impossible to detail the exact contribution of the HYV's. Instead, about all we can do at the moment is to provide a general idea of some of the overall relationships in terms of the HYV package.

1. Overall Changes in Yield

Perhaps the most obvious approach is to examine overall changes in yield and then relate these back to the adoption of HYV's. Changes in national wheat and rice yields for the countries noted in the previous section are depicted in Figures 7 and 8.

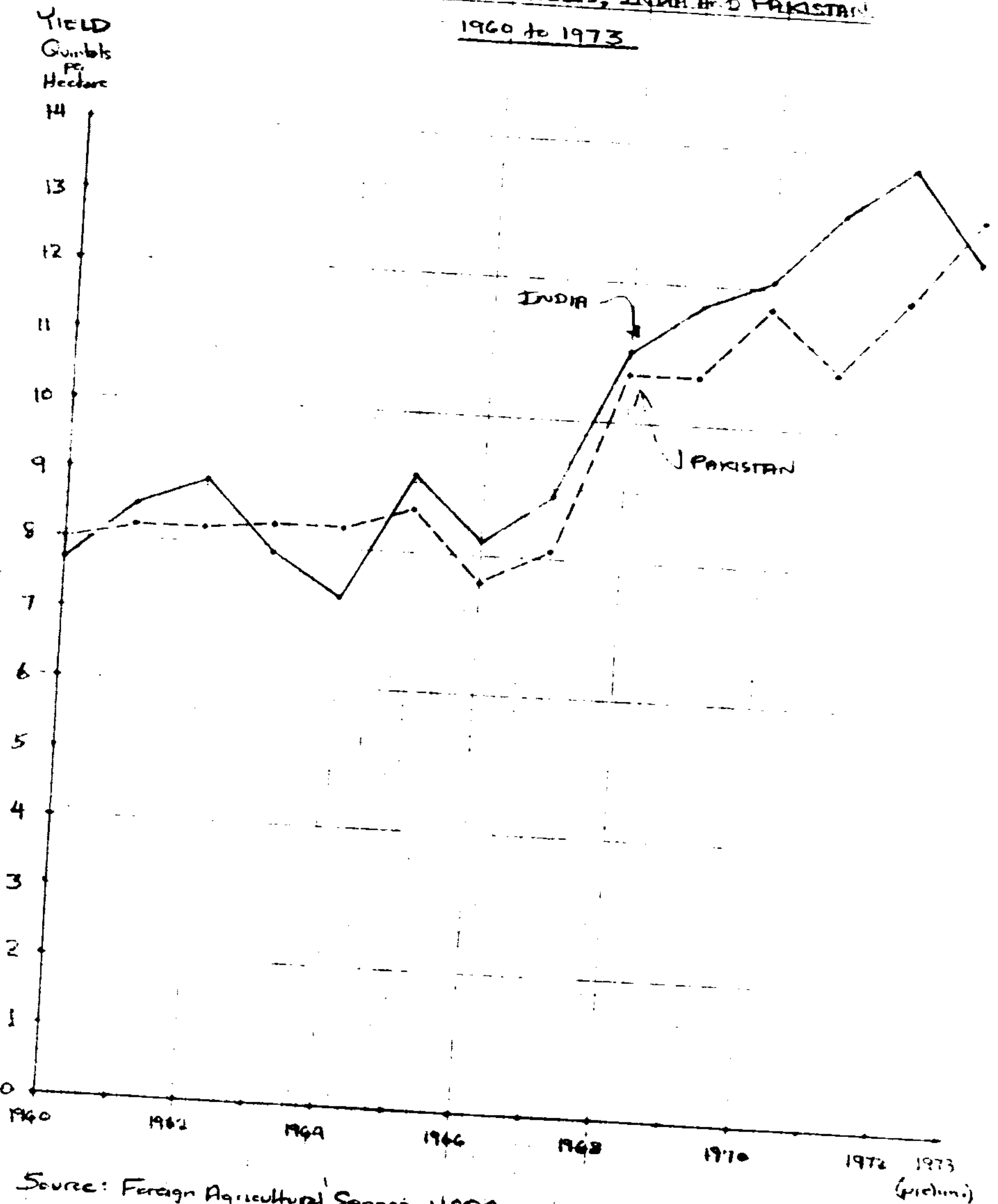
The following trends were apparent:

- Wheat (Figure 7). Yields were relatively steady in India and Pakistan through 1967, and then rose sharply in 1968. 17/ Indian yields continued to rise through 1972, but dropped in 1973. Pakistan's yields moved up more slowly but continued to rise in 1973, exceeding Indian yields.

- Rice (Figure 8). 18/ Yields in three of the four countries (excluding India) either remained about the same or rose only gradually

Figure 7, TRENDS IN WHEAT YIELDS, INDIA AND PAKISTAN

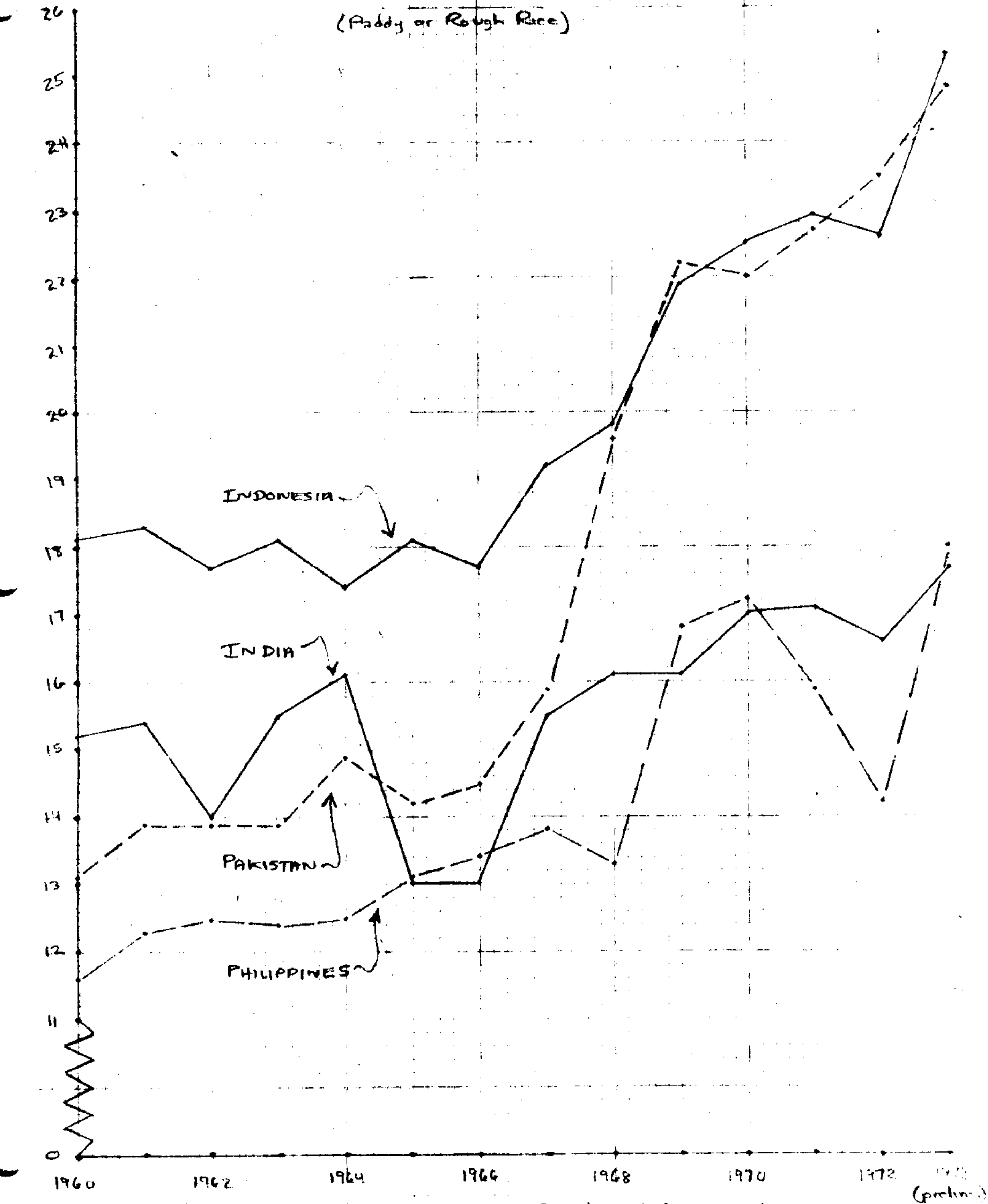
1960 to 1973



Source: Foreign Agricultural Service, USDA.

Figure 8. TRENDS IN RICE YIELDS, INDIA, INDONESIA, PAKISTAN, AND PHILIPPINES, 1960 TO 1973
(Paddy or Rough Rice)

YIELD
Quintals per Hectare



Source: Foreign Agricultural Service, USDA. Pakistan data from A. Gill, ERS through 1966, 1967, or 1968, and then increased fairly sharply. Pakistan and Indonesia showed the sharpest and most persistant gains. The Philippines (and Malaysia) moved up more moderately. India has shown only a gradual increase over the period. Yields dropped in three of the four countries in 1972, but increased in all in 1973.

Not surprisingly, these yield trends roughly coincide with the expansion of HYV area in each country (except for the drop in Philippine rice yields in 1971 and 1972) as reported in Figures 4 and 5. The impact, however, seemed to be least for rice in India--probably because (a) the HYV area only represented a small proportion of the total area, and (b) the HYV's used in India have not yet proved to be well suited to local monsoon conditions.

The big overall unknown is how much of the increase in yields was due to weather. Weather normally has considerable influence over year to year variations but has less influence over long term trends. Most of the countries showing an increase in yields have continued it over a 4 to 5 year period. Even with the leveling off or drop off in rice yields in the poor crop year of 1972, they were still above those found in the early 1960's. And they rose even higher in 1973. Thus it seems that more than weather was involved in the expansion of yields.

2. Comparative Yield Levels

Some national data are available which give an idea of the relative yield levels of the HYV's compared to traditional varieties. These data, however, can be misleading because, as noted earlier, the HYV's are usually planted on the better land. Even so, it may be of interest to see what the official statistics say and compare them with other measures.

a. Official National Statistics

While relatively few figures have been pulled together, we do have a few examples.

India, West Pakistan, and Turkey. One USDA report summarized such information for wheat from 1966 to 1970 for these three countries. 19/ It revealed that:

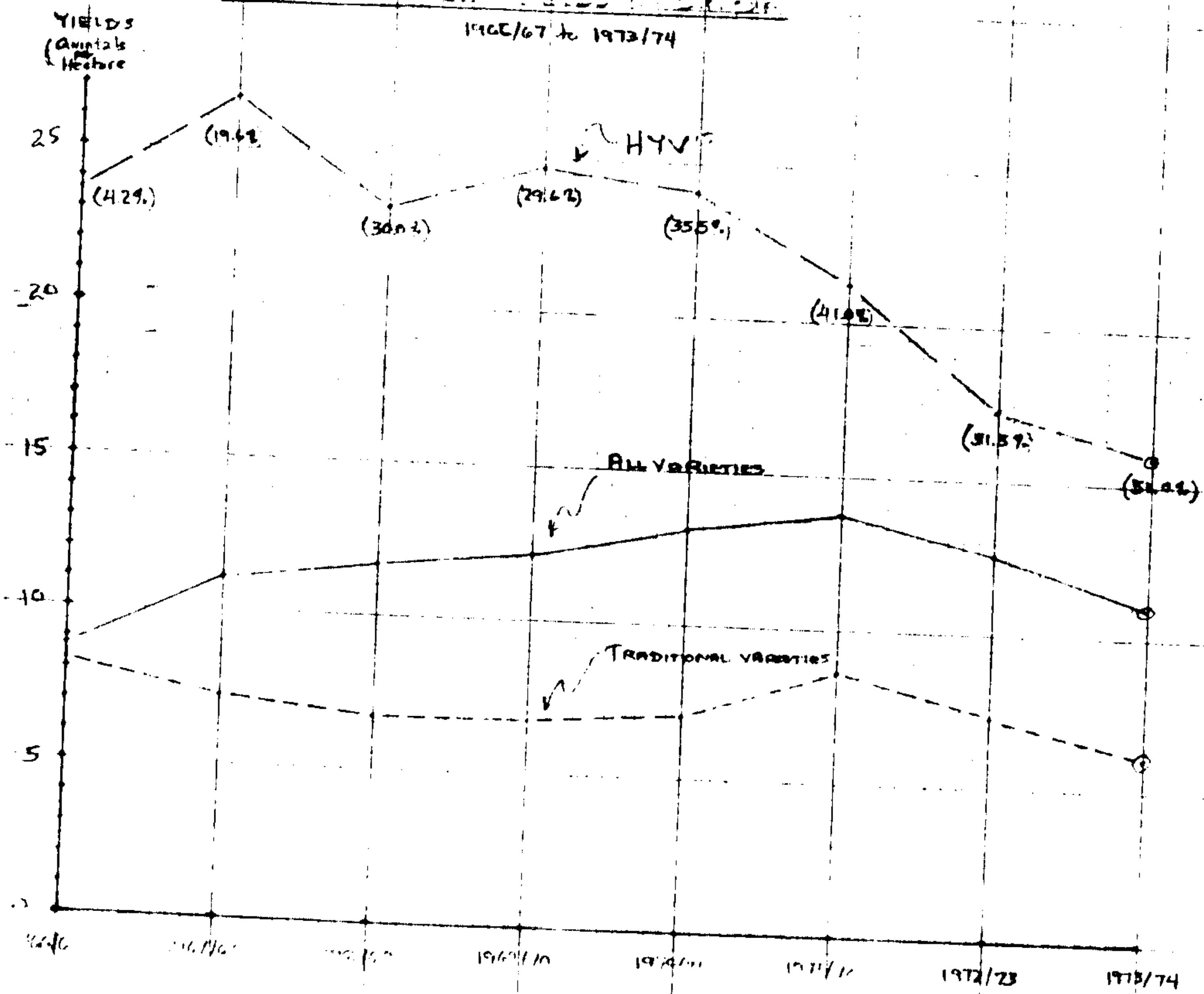
- The HYV yields were substantially above local varieties - from 1.77 to 3.70 times as great.
- As the area planted to HYV's expanded, their yield levels dropped, though not evenly.
- As the HYV area expanded, the national yield levels increased.

These relationships would be expected. The drop in HYV yields might be surprising at first, but not when the changing quality of land base is recalled. Because of the higher yields, the HYV's account for a larger proportion of total production than they do of total area. The multiple, however, decreases as the average HYV yield level decreases over time.

India. Similar data are available for wheat and rice for the period from 1966/67 through 1973/74 (Tables 9 and 10). 20/ They show the same

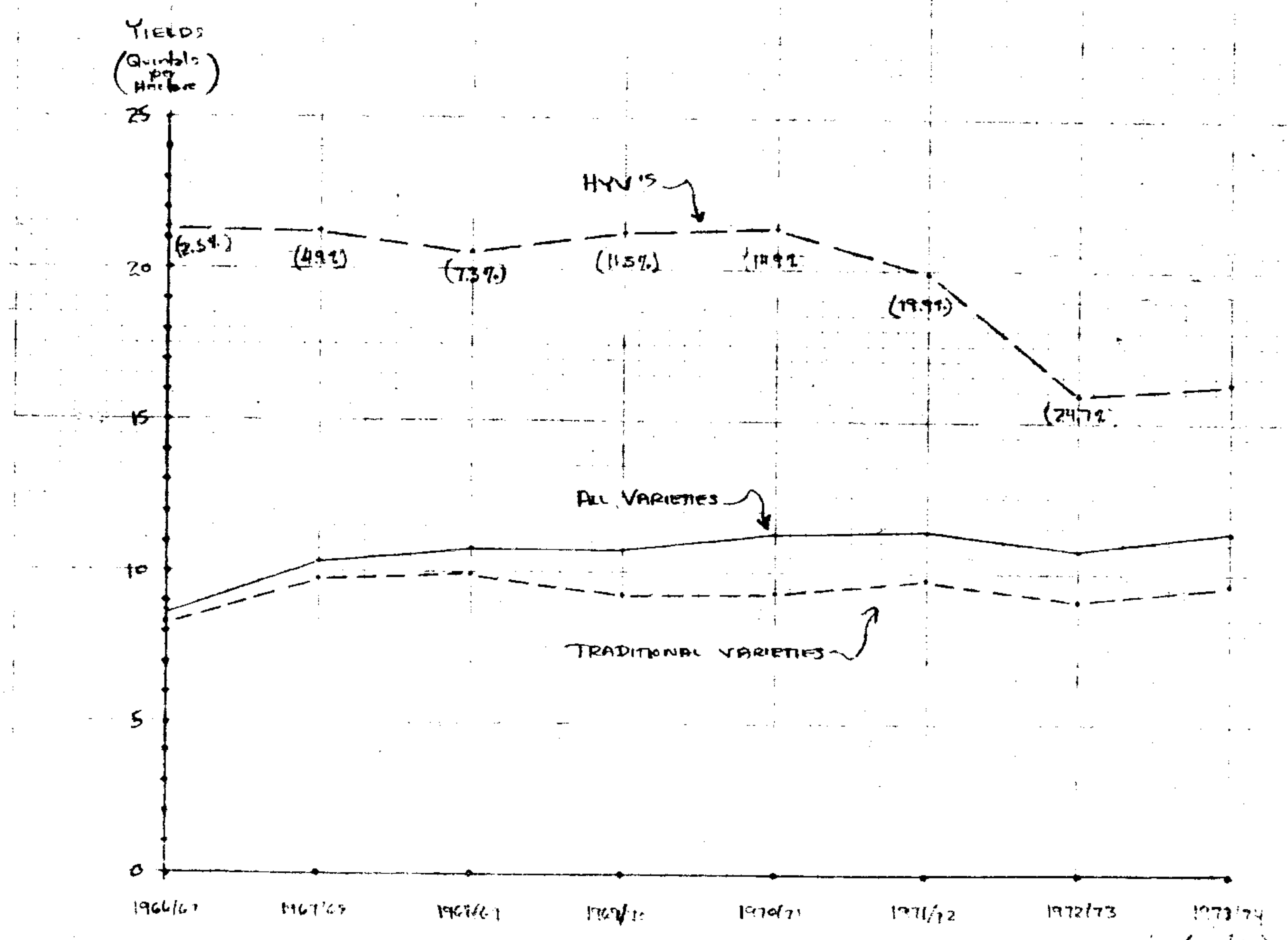
Figure 9. TRENDS IN [illegible]

1966/67 to 1973/74



[illegible] ERS/USDA

Figure 10. TRENDS IN RICE YIELDS IN INDIA 1966/67 to 1973/74



Source: John Baker, ERS/USDA

general trends noted above, with a few variations. The yields of the HYV's in India were from less than two to more than three times as high as the traditional varieties. The wheat multiple was constantly higher than the rice multiple, though the difference narrowed later in the period. These ratios were fairly consistent through 1970/71, and then dropped.

Crop Year	HYV Yields in India as Multiple of Yields of Traditional Varieties	
	Wheat	Rice
1966/67	2.87	2.58
1967/68	3.70	2.18
1968/69	3.49	2.05
1969/70	3.68	2.26
1970/71	3.44	2.27
1971/72	2.50	2.03
1972/73	2.35	1.76
1973/74	2.59	1.71

- Wheat (Figure 9). The HYV wheat yields in India held relatively steady through 1970/71 (when 35.5% of the total wheat area was planted to them), and then dropped fairly sharply from 1971/72 on. Yields of traditional varieties at first dropped slightly and then rose in 1971/72. While yields of HYV wheats dropped in 1972/73 and 1973/74, so did yields of traditional varieties. In relative terms, the traditional varieties dropped more than the HYV's in 1973/74:

1973/74 Yields as Proportion of	HYV	Traditional
	- precent -	
1972/73	92.5	84.2
1971/72	75.3	72.8

Thus, during 1972/73 and 1973/74, both types of varieties appear either to have been hit by the same factors, or suffered similar reactions to different forces. In 1973/74 these appear to have included cool, dry weather. There is also, as might be expected, a diminishing availability of land which can be brought into cultivation without further increases in irrigated area. 21/

- Rice (Figure 10). Like the HYV wheats, the yields for the HYV rices in India held fairly steady through 1970/71 (when they occupied 15% of the total wheat area) and then dropped fairly sharply from 1971/72 to 1972/73. The yield of traditional rice remained relatively level, while the yield of all varieties increased slightly through the period, except for a slight dip in 1972/73. As with wheat, both the HYV's and the traditional varieties dropped in 1972/73, although in this case the HYV's dropped more. The main problem, as is well known, was the widespread drought.

Philippines. 22/ Official estimates for rice over the 1968-1972 period suggest that HYV yields averaged from 1.30 to 1.35 times those of traditional varieties.

b. Deflated Comparative Yields

If the land base were standardized, the above comparative yield levels would be somewhat lower. Based on a rather unscientific combination of sources and hunches several years ago, I assumed--when pressed for a rough estimate--that the HYV package in irrigated areas might result in a relative yield ratio of 2.0 for wheat and 1.25 for rice. 23/ The ratios would be lower in unirrigated areas. 24/

Recent survey data for the Philippines suggest that I may have been on the high side for rice. As compared to the overall ratio of 1.30 to 1.35 reported above, survey data revealed that when upland rice was omitted from the calculations (since HYV's are of no consequence in upland regions) the ratio dropped to 1.19. If rainfed lowland rice is in turn sorted out (because HYV's represent a small portion of this zone), the ratio dropped to 1.10. 25/ That is, on irrigated hard, the HYV's yielded about 1.1 times as much (or 10% more) than traditional varieties. On the other hand, it was found that the multiple did not decline in any pronounced fashion over the period; perhaps the arrival of improved varieties compensated for the possbility that lower quality land may have been planted to the HYV's.

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Obviously we need to know much more about actual realized yields at the farm level before we can make very precise evaluations of the contributions of the HYV's or the HYV package to increased yields and increased national production. 26/ No reasonable person would expect the yield jumps obtained in experiment station trials to be repeated on the average at the farm level. Part of the reason that realized yields from the HYV's may be less that anticipated relates to the level of use and quality of inputs making up the HYV package. These will be discussed in some detail in the next chapter. But in any case it seems clear that the HYV package has had a significant, if imprecisely measured, direct impact on wheat and rice output in the countries where they have been widely adopted. The indirect effects on output of other crops, through facilitation of multiple cropping programs, may also be of considerable significance.

IV. PROSPECTS FOR THE INPUT PACKAGE

The "green revolution", while generally characterized in terms of the high-yielding varieties of seeds, as I have suggested, in reality is composed of a package of technologies. The HYV's are the necessary condition, but they are not sufficient. In addition to improved management, they must be accompanied by adequate fertilization. Improved water control and insect and disease control are also usually involved. If anyone of these is lacking, the potential offered by the varieties may not be realized. The inputs, therefore, may individually and/or collectively become the weak link in the chain of events that must take place to make a "green revolution" possible. Prospects for the future of the "green revolution" on the supply side largely depend on the relative importance and availability of these inputs.

A. Seed Multiplication and Distribution

At this point in the "green revolution" there is a tendency to take seed for granted. Some may think that the difficult job is done when the plant breeder releases new varieties. In the DC's this would be the case: many commercial seed firms are available and do a fine job of seed multiplication and distribution. The situation, unfortunately, is not so well in hand in the LDC's.

Most LDC's simply do not have a highly advanced seed industry. Indeed, FAO has recently suggested that the lack of a commercial supply of high quality improved seeds has been "one of the main bottlenecks limiting the rapid and sustained spread of the HYV's." 27/ This may not matter so much at first when areas are limited and reliance can be placed on imported seed. But within a few years and as area planted expands, seed must usually come from domestic sources.

Moreover, varieties developed at the international centers must often be tailored to local needs. National adaptive breeding programs are as yet not always up to the task. According to one reporter who recently spent 10 days touring rural villages in the Punjab in India:

> The farmers' chief complaint was that there is no good seed. They said that the first three new wheat varieties introduced in the late 1960's - Khalyan Sona, PV-18 and 308 - were the only good ones and that those put out by Indian research institutes since 1971 had been fiascos, either rust-prone, subject to insects, just plain low-yielding or with serious environmental problems. 28/

One can only hope that this overstates the actual problem.

A further, more pervasive, difficulty is that the domestic seed stock tends to be diluted in quality over time. In many LDC's it is "frequently reported that farmers receive adultered or deteriorated seeds as a result of negligence or lack of scruples on the part of the distributor." 29/ A recent journal article notes that farmers in India's Punjab "generally complained of defective seed quality after 1967/68'; the author felt that "mixing of lower quality seed with better seed occurred at more than one level of the seed distribution channel." 30/ The problem is not entirely the distributor. According to another report from India.

> Farmers trying to skimp on their expenses have tended not to buy the new hybird seed and instead have used seeds they've saved from the previous crop or brought cheaply from friends. As a result, fields....are jagged with stalks of every height. Each acre contains half a dozen different varieties. 31/

As a consequence of such problems, a leading Indian plant breeder concludes that "seed arrangements are miserably bad." 32/

Just how improved seed distribution can best be obtained in LDC's is an open question. Some countries have relied on government seed corporations, but these have not had a notable record of success. In some, cases, in fact, they have been more of a hinderance than a help. There is a feeling in some DC's that the seed business is best lest to private enterprise or large cooperatives, but that stringent government administration of quality control standards is needed.

I don't have the answer. But we must recognize that quality seed multiplication and distribution--while perhaps not a terribly exciting matter--is of vital importance and cannot be taken for granted in most LDC's. It is the first order of business if the "green revolution" is to be maintained or expanded in the future.

B. Water Control 33/

The provision of an input package involves a greater investment per acre on the part of individual farmers. Unexpected variations in weather can make this investment a risky venture. Perhaps the most significant weather variable in LDC's is water supply or rainfall. Associated problems of drainage can also be important for some crops in some irrigated areas. Supply and drainage are often combined in discussions under the rubric of water control.

Precise water control is most easily obtained under irrigated conditions. Hence much of the HYV area of wheat and rice is grown under irrigated conditions. Precise figures are not available, but it is estimated that roughly 2/3 of the HYV wheat and nearly all of the HYV rice are irrigated to some extent.

- Wheat. The irrigated wheat area is principally found in India and Pakistan. Some important regions in South Asia (such as the barani or rainfed portions of Pakistan) recieve little if any irrigation. The same is true of much of the wheat raised in the Near East and North Africa. Since wheat is usually raised in more arid regions, the problem of water supply is of more importance than drainage.

- Rice. The irrigated rice area in South and Southeast Asia constitutes only about 20% of the total area planted to rice (Another 50% is rainfed lowland, 20% rainfed upland and 10% deepwater). HYV's can be raised in the rainfed lowland areas, but the rainfall uncertainty means that yields may be only slightly higher.

1. <u>Irrigation</u>

Both the quality of irrigation systems and the need for irrigation vary widely in the developing nations. Irrigation systems range from virtually complete year-round supply to occasional supplementation of rainfall. Most commonly, the systems supplement rainfall during the wet season and service only a limited area during the dry season.

a. <u>Differing Water Requirements</u>

Water requirements of wheat and rice vary sharply. Rice, which is largely grown under flooded or paddy conditions, requires much more water per unit of land than wheat. Thus, rice is usually raised in monsoon areas and wheat in the drier climates. Similarly, rice is more often grown during the warm wet (summer) season and wheat during the cooler dry (winter) season. In some instances, where growing seasons permit, they are able to follow each other in multiple cropping rotations (such as in Punjab and Uttar Pradesh states in India).

While rice tends to be a monsoon season crop, it can be, and is, raised during the dry season if the weather is not too cool and if irrigation is present. Irrigation in turn makes more precise water control possible. The late dry season also provides other cultural advantages: sunlight is abundant, mechanical operations can be performed at any time, weed control is easy, pests are easier to control, and harvesting is less hazardous. For these reasons, and because of difficulties in developing varieties well adapted to monsoon seasons (as is still the case in India), a significant portion of the rice HYV's in some countries are planted during the dry season:

- -1967/68 season. 30% of the HYV area in India 34/
- -1972/73 season. 42% of the HYV area in Bangladesh, 33% in Indonesia, 53% in Ceylon, and 58% in Thailand.

The difficulty with this practice is the relatively high water requirements for rice--roughly three times as much as for wheat.

b. Source of Irrigation Water

Irrigation water is provided by a variety of sources including canals, wells, and ponds. In South Asia, canals are the leading single source in terms of overall volume. In India, they are estimated to account for roughly 40% of the total, while in Pakistan they represented 72 to 83% of the total in the late 1960's. Wells are the second major overall source, accounting for some 34% of the total in India (followed by ponds with 17%, and other with 8%). 35/

Power tubewells have become particularly important in areas where the HYV's have been raised in South Asia. The growth in their numbers has roughly paralled the expansion in HYV area in India and Pakistan. Curiously, much of this growth occurred in areas already irrigated by large scale canals. In Pakistan in 1969, 42% of the private tubewells were on canal irrigated land while 58% were not. There is reason to believe, however, that the others were not far away: a 1966/67 study revealed that only 18% of the tubewells were more than 5 miles from rivers or canals. 36/

The reasons for this affinity are not hard to find: (1) there are many limitations to the use of canal water and farmers have turned to tubewells to more dependable water supplies and better water control; (2) the seepage from canals and rivers helps recharge the underground water tapped by the tubewells. A number of studies have revealed higher yields on land irrigated by tubewells than by canals. For these reasons, tubewells in or near canal-irrigated districts have played a more important role for the "green revolution" in South Asia than other overall capacity might suggest.

c. Influence of the Energy Crisis

Tubewells are powered by both diesel and electric engines. In Pakistan in 1969, the division of power sources was as follows: 37/

	Diesel	Electric
	- percent -	
Private Sector	61	39
Public Sector	0	100
Weighted total*	45	55

*Weighted by million acre feet pumped by private and public sectors

Both sources have energy related problems.

The problem with electrical power in many LDC's is its unreliability. Electric power in South Asia, for instance, is usually derived from hydo-electric sources. These in turn depend on rainfall. When drought strikes, hydroelectric power supplies become erratic. This happened in India several years ago, and is a recurring threat. It has led some farmers to install diesel-powered pumps.

The problem with diesel power is one of both cost of diesel fuel and availability. Even before the energy crisis, the annual private cost of operating a diesel-powered tubewell was about twice as high as for an electric-powered tubewell in some regions in India and Pakistan. Diesel oil prices began to rise sharply in Pakistan as early as November 1973(24% over October prices)--and even then the rise in diesel fuel price was less than for other uses. A certain subsidization of the diesel fuel price might be justified in Pakistan becuase the social costs of diesel tubewells are, or were in the 1960's, only about 2/3 of the social costs of electric-powered tubewells (electrical rates benefit from a vast social investment in infastructure). 38/

Added to the price problem is one of sheer availability of diesel fuel. During late 1973 and early 1974, fuel supplies for tubewell use in some regions of South Asia were reduced. The effect at the local level in the Ludhiana area of India was eloquently reported in a recent article:

> The other day outside the town of Khanna, gas station owner Bulbir Singh Gill shook his head as he walked along a line of more than 100 farmers.
> Some of the turbaned, bearded Sikhs had been waiting outside Gill's stations for three and four days, sleeping alongside their drab jerry cans, waiting for their weekly 5 gallon quota of diesel.

> "It's too late now to help the crop" said Banta Singh Mann, who had pedalled the 40 miles to Gill's station three days earlier. "Now we're saving our ration for the thresning." 39/

Obviously if diesel fuel remains a scarce commodity, smaller quantities may be available to use on wheat and rice. Moveover, if prices for these crops are low farmers may begin to consider reallocation to potentially more remunerative crops. Some of these, such as cotton, might be in the non-food category. Or farmers might simply shift to crops with lower water requirements. At least some Indian farmers are reportedly thinking of returning to the use of bullock-powered Persian wheels. 40/

Just what will happen will depend to a large degree to what policies are followed by national governments with respect to pricing of both fuel and agricultural products. The longer-run effect will also depend on how possible it is to (1) extend electrification to areas where pumps are presently powered by diesel engines and (2) increase the reliability of supply. And clearly the improvement of, and possibly expansion of, canal irrigation takes on new priority. Other government policies may also be important. 41/

2. Adapting to Less Irrigation

Since the energy crisis may both result in less water being supplied in areas heretofore covered by diesel tubewells, and limit future growth in this form of irrigation, other alternatives need to be considered. Beyond examining other sources of energy or of irrigation water (such as canals), the most promising approach would seem to be to try to develop schemes or methods for adapting to less water.

Fortunately we do not start from point zero. The fact that HYV's in the past have largely been confined to irrigated years has not gone unnoticed. Several years ago the International Agricultural Research Institutes stepped up studies on dryland culture. Some of this work, paradoxically, may be of relevance to some of the more poorly irrigated areas. It has taken several main forms: breeding and selection for drought tolerance and quick maturity, new cropping systems, and development of systems to enhance moisture retention.

a. Wheat 42/

As noted, the HYV's of wheat are already planted in non-irrigated regions to a significant degree (perhaps 1/3 of the total area). 43/ And on these regions thay yield at least as well as traditional varieties. In some of the dryer areas, however, it may be necessary to use mechanization in order to secure adequate seedbed preparation or to be able to sow at the proper time. 44/

One of the main objectives of the wheat improvement program at CIMMYT is to develop more effective resistance to unfavorable moisture conditions. This is being attempted in two ways. First, the breeding program is trying to transfer the drought tolerance characteristics of winter wheat to spring wheat (winter hardiness and drought tolerance are believed to be related). Another alternative may be provided by a wheat x rye cross known as triticale which promises to have pronounced drought (and cold) tolerance.

Secondly, CIMMYT is studying various cultural practices such as (1) normal fallow-wheat rotations, and (2) a forage legume-wheat system. The latter system is being examined in Africa where weed problem exists during normal fallow (the weeds, which are consumed by sheep and goats, are of low nutrient value and use up soil fertility and moisture); it promises to reduce weeds and at the same provides much improved forage for an animal-cereal operation and nitrogen for the succeeding grain crop. Other methods of weed control are also being examined.

b. Rice 45/

The search for tolerance in rice takes two quite different directions: (1) adaptation to deficit water supplies, and (2) adaptation to surplus water. It will be recalled that about 10% of the rice area in East and South Asia is what is known as deepwater. The dwarf and semi-dwarf HYV's do not, for obvious reasons, do as well under these conditions as taller traditional varieties.

It has been found that the present HYV's vary in their tolerance to surplus or deficit water. Philippine farmers, for example, discovered that one variety (IR5) was able to recover from early drought, and the variety was spreading rapidly in that country's rainfed acreas until it was struck down by virus in 1971. At IRRI, some upland varieties with a measure of tolerance have been identified in crossing programs. A genetic characteristic that permits rapid elongation has also been incorporated in dwarf HYV's: when water is at normal levels, the plants remain dwarf; but if the water level rises, the plants elongate and successfully overcome as much as a meter of water. Furthermore, trials have shown that nitrogen applications combined with weed control sharply reduced, up to a point, the effect to drought on yields.

In terms of surplus water, Thai farmers found that the first high-yielding Thai varieties (RD1 and RD3) were too short to be planted in the wet season in areas subject to flooding. The most recent Thai release (RD5) is 50 percent taller than the earlier releases, and should be acceptable over a much wider area. Considerably further research work is now being carried out on water tolerance.

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While irrigation can be extended in many areas and plant tolerance to variations in water supply improved by breeding, the process takes time and money and faces upper limits. Water differs from the other inputs of the "green revolution" in that it cannot be purchased from the local agricultural supplies dealer. A close and exacting symbiosis with nature is required.

C. Plant Nutrition (Fertilizer)

Much concern has been expressed about the possible harmful effects of the current fertilizer shortage on the progress of the green revolution. This concern is well placed. The region of the world which have benefited most from the "green revolution", especially South Asia, are precisely those where the chemical fertilizer shortage is the greatest.

1. Present Fertilizer Situation

The current world fertilizer shortage is not due to a sudden and sharp growth in LDC fertilizer use. LDC fertilizer consumption, while expanding at a greater percentage rate than the DC's, is still relatively small compared to the DC's. 46/ The LDC's are, however, caught up in the world shortage because their production is generally low and a significant portion of consumption is imported.

Levels of chemical fertilizer use vary widely in the LDC's but in general are well below those in the DC's. In 1971/72, for instance, total chemical fertilizer use in the non-communist LDC's was (a) only 15% if the DC's in terms of application per hectare of arable land, and (b) only 10.5% of the DC's in application per capita. Within the LDC category, overall fertilizer use was highest in Latin America and lowest in Africa; Asia fell in between. 47/ Within individual LDC's, there is a range from large areas which receive no chemical fertilizer to relatively smaller areas which may be heavily fertilized.

In 1972, imports of fertilizer represented a sizeable proportion of LDC consumption. The approximate breakdown for non-communist LDC's by nutrient was as follows: 48/

Nutrient	Consumption	Imports	Proportion Imported
	- million metric tons -		- percent -
N	5.7	2.9	50
P	2.7	1.4	51
K	1.5	1.5	99
Total	9.9	5.7	58

Relative imports were greatest in Africa and least in the Far East. Domestic production of fertilizer has been increasing by fits and starts in South Asia, but imports have been rising at an even greater rate.

For most LDC's we have very little information on how fertilizer is actually distributed by crop. One of the rare sets of estimates, for India, suggests the following breakdown for nitrogen fertilizer in 1970/71: 49/

Crop	Percent
Rice	34.0
Wheat	12.0
Other grains	19.7
Pulses	6.6
Other 1/	27.7
Total	100

1/ Sugarcane, cotton, spices, vegetables, tobacco, other.

There is some feeling that the rice figure may be high and the wheat proportion low. It is also not clear whether adequate account has been taken of fertilizer use on tea, coffee, rubber, oil seeds, etc. A more detailed estimate for Mysore State in 1972/73, however, suggests a roughly similar breakdown: 50/

Crop Group	Percent
Rice, Jowar (sorghum), maize, bajra (pearl millet), wheat	59
Sugarcane, cotton, tobacco, chillies potatoes and other plantation crops	18
Oilseeds, pulses, mics. crops	12
Bagi (finger millet), barley, & other minor millets	11
Total	100

The actual use pattern in any one region would of course vary as relative product prices changed. Generally, however, it is thought that the most profitable crops, such as the sugarcane etc. category noted above, or fruits and vegetables, would be able to outbid the other uses.

2. Fertilizer and the HYV's

It is too early to say precisely how much of an impact the chemical fertilizer shortage will have on the HYV's. Yields are determined by many natural and human factors of which fertilizer is only one. Some countries such as Burma, Thailand, and Bangladesh make relatively little use of fertilizer, while others such as the Philippines, parts of India, and Indonesia make heavier use. 51/

a. Levels of Fertilizer Use

Within a given LDC, we do not know how much of the chemical fertilizer used for grains goes to HYV's and how much goes for traditional varieties. Nor do we know much about the comparative doses actually applied. According to one study of Philippines rice farmers, the use of fertilizer was more common for HYV than for non-HYV growers, but there was a negligible difference in the average quantity used per farmer. 52/ It would be helpful to know how typical this situation is.

Several statements are available, however, which reveal that when LDC farmers use fertilizer on HYV's the dosages have in general been well below the recommended levels. In India, various investigations have shown application rates on wheat of only 40 to 63% of recommended levels in the Punjab and 25 to 33% in Bihar. 53/ Another study of wheat farmers in the Multan area of Pakistan in 1969/70 revealed that 11% of the farmers used no chemical nitrogen and the best that could be said of the rest was that 72% used at least 1/2 of the minimum recommended level of nitrogen. 54/ Studies of rice farmers in the Philippines during the 1969/70 wet season indicated that only 2/3 of the farmers used commercial fertilizer, and of these only 1/3 used the recommended rate; during the dry season only 60% of the farmers used fertilizer. 55/ According to an earlier estimate in the Philippines the actual rate of nitrogen application was less than half of the recommended dressing. 56/ Only one account has been found of most farmers using close to recommended levels (IR-20 rice farmers in Bangladesh). 57/

b. Factors Influencing Application

The relatively low general level of use may come as a surprise in view of what has been said about the importance of fertilizer to the HYV's. It may reflect many factors such as: (a) a relative lack of other complementary technologies, (b) higher prices for fertilizer and lower prices for grain than were used in drawing up the recommended application levels, (c) a desire of the farmer to minimize risk rather than to maximize profits. The second factor may lead to a lower economic optimum level of use than anticipated.

And it may be that in some areas part of the difference is made up by animal manures; this is a common practice in the Punjab of Pakistan and in one survey in Bangladesh, 75% of the rice farmers raising IR-20 were using cowdung. 58/

Another factor may be that paddy rice is able to generate some of the nitrogen it needs. According to a recent report from the International Rice Research Institute:

> IRRI researchers have discovered that atmospheric nitrogen can be "fixed" in paddy soils in a farm that rice plants can use. The equivalent of 60 kilograms per hectare of nitrogen has been fixed in some experiments. This may explain how rice has been grown continually on the same paddy fields, without fertilization, for hundreds of years. 59/

Only low rates of nitrogen fixation have been observed, however, in upland soils.

Finally, it should be recognized that HYV's, which are usually raised under paddy conditions, usually do as well as traditional varieties without fertilizer, and may even yield slightly more. For a given level of fertilizer use, they usually yield more than the traditional varieties (See generalized curves in Figure 11). 60/

Thus some farmers can obtain a slight boost at no cost, or can reach the most sharply rising portion of the HYV response curve without reaching the recommended levels of fertilizer use. This situation does not, however, diminish the importance of getting more low cost fertilizer to HYV farmers. Rather it suggest that more attention needs to be given to the economic and technical factors restraining fertilizer use at the farm level.

3. Responding to the Fertilizer Crisis

The potential of the HYV's is hardly apt to be attained if the present rather low levels of fertilizer use drop even more due to sacarcity and sharply higher prices. Responses to the crisis have tended to apply to either the chemical fertilizers or to substitutes for chemical fertilizers.

Figure II. GENERALIZED FERTILIZER RESPONSE CURVES

Rice and Wheat

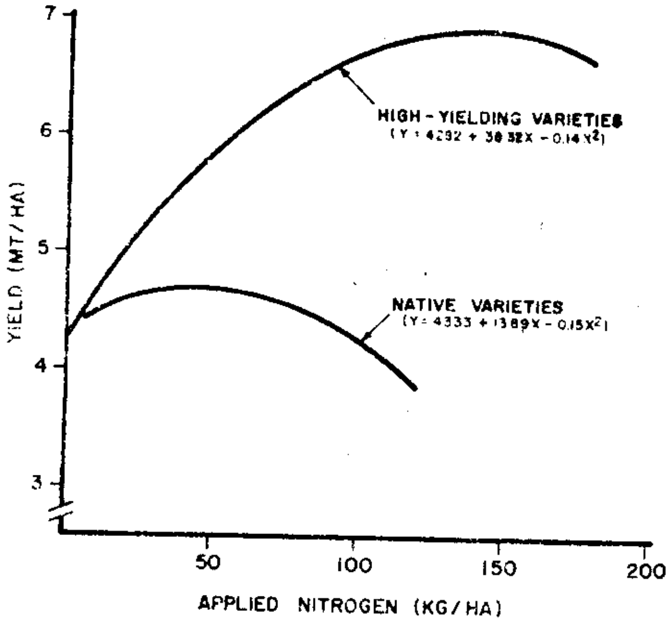

Figure 1. Generalized curve for the response of rice to nitrogen applications in the dry season

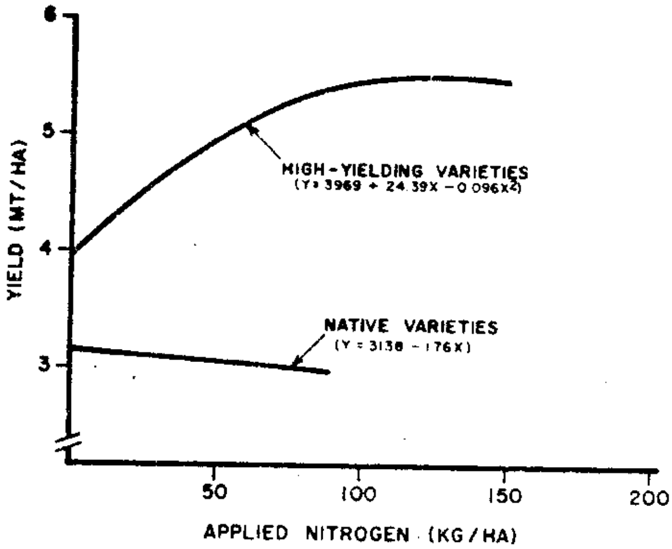

Figure 2. Generalized curve for the response of rice to nitrogen applications in the wet season.

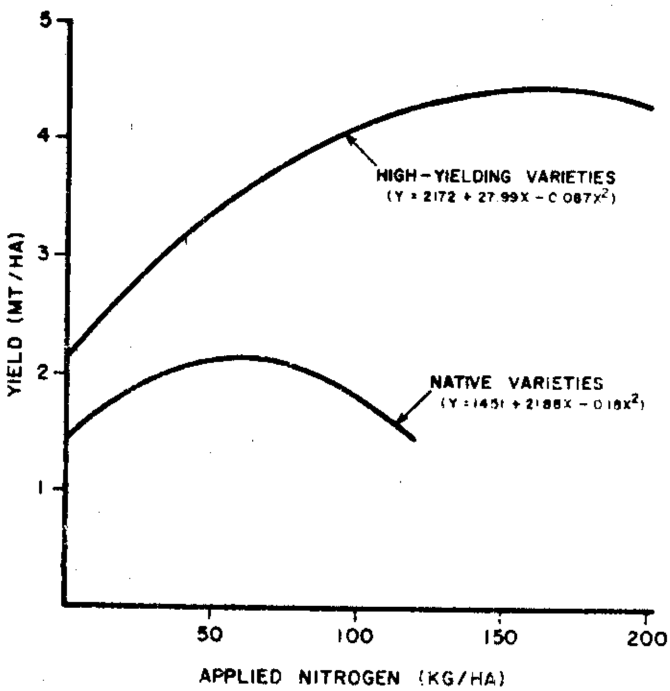

Figure 3. Generalized curve for the response of wheat to nitrogen applications.

Source: High-Yielding Cereals and Fertilizer Demand, TVA, 1970, Bulletin Y-4, pp. 6,7,8.

a. Chemical Fertilizers

In turn, recommendations for improving the chemical fertilizer situation, aside from an expansion in fertilizer production, are usually of an economic or technical nature.

(1) Economic Policies. Several studies have suggested that the farm demand for fertilizer is inelastic in the short run and elastic in the longer run. Thus for a given percentage increase in prices, consumption will decline by a smaller percentage in the short run and by a larger percentage in the long run. And the decline may ultimately be greater among those who have only recently taken up fertilizer use. Since the new adopters are more likely to still be on the steep part of the response curve, the effect on output may be greater than for those who have utilized fertilizer for some time at higher levels. 61/

One way to react to this situation is for the government to subsidize fertilizer prices. This has been a common practice over the years in many LDC's. The problem is that this procedure can distort the market mechanism and can lead to inefficiences in resource use. It is also expensive for the government. A recent news item from Manila, for example, states that:

> The Philippines in an effort to keep controls on fertilizer prices at the retail level has paid out more than $30 million in direct and indirect subsidies to importers, but government officials say the subsidies cannot be continued through 1974. 62/

Moreover, to complete the economic equation, account must be taken of the price of agricultural products. These can, depending on the degree of government price support, also fluctuate sharply. Thus the ratio of fertilizer and product prices can vary notably within and between countries.

Fertilizer will, of course, tend to be used on the crops with highest returns; these may not always include the food grains. To direct use to grain HYV's, therefore, the government may have to give close attention to relative product prices and to possibly raising procurement prices.

Other more esoteric and theoretical ideas would be based on differential response curves and the locating along them. One idea is to place a ceiling for individual fertilizer use per unit of land. This ceiling would be at a point where the response curve begins to lose momentum. The fertilizer saved by this practice would be redirected to those who are at an earlier point on the response curve (as shown in Figure 11). This could be done within a country or between them--such as directing more fertilizer from the DC's to the LDC's. A second idea might be to limit fertilizer use to the HYV's wherever they have a higher response curve than the traditional varieties. To some extent the first proposal might be accomplished automatically through the operation of the pricing system: farmers obtaining a greater response from the addition of fertilizer might, depending on the degree to which perfect markets prevail, be expected to pay a higher price than those experiencing a smaller response. In any case, these proposals are more theoretically intruiging than practical.

In short, there is some question as to how much can be effectively accomplished through economic policies in the LDC's in other than the short run.

(2) More Efficient Use. Although fertilizer use in the LDC's is relatively low, it may also be rather inefficiently utilized.

Transportation and storage may be inadequate. Losses may be high. Specific fertilizer needs of specific soils may not be well known. Poor water control may hinder nutrient utilization. Fertilizer may be applied at the wrong time and/or in the wrong dose. Complementary cultural practices--such as better weed control and water management practices--may not be well utilized. Development of slow-release forms of nitrogen such as sulfer-coated urea may provide a sharp boost in efficiency on crops such as rice. 62/ Much more can be accomplished in these areas.

b. Organic Fertilizers

With a shortage of chemical fertilizers, considerable attention has recently been given to organic fertilizers. These in turn cover a wide range of products and activities. No attempt will be made to go into them all here. Suffice it to say, as we have noted earlier, than some forms such as animal manure have been used on HYV's.

What of prospects? One approach is typlified by the recent appeal of the Minister of Agriculture in India to state government to: "Mobilize all their resources of town and village compost, sewage and fullage irrigation, green manures and other natural waste to supplement chemical fertilizers." 64/

There may be many more opportunities for combining the relatively shorter season HYV's with legumes in multiple cropping systems. In some cases legumes, which are high in nutrient value and which generate their own nitrogen, might be substituted for HYV wheats and rices. The International Rice Research Institute, which as noted earlier has found that paddy rice fixes some nitrogen, states that:

> We hope to find ways to increase the efficiency of nitrogen fixation, and to determine the conditions under which the plant best uses the fixed nitrogen. We are screening rice varieties to determine their relative nitrogen-fixing capacities. Perhaps in the future, rice varieties can be selected which encourage high rates of nitrogen fixiation and which use fertilizer and soil nitrogen more efficiently. 65/

Other biological forms of nutrient generation are under study. 66/ While all of these methods can, as noted, supplement chemical fertilizers, they are limited at the moment in potential. For the short run, the HYV's will basically have to rely on chemical fertilizer. To provide the technological base for more efficient use of chemical fertilizers, as well as to investigate organic and biological forms over the longer run, Secretary of State Kissinger has recently proposed the establishment of an International Plant Nutrition Institute.

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On balance, it seems quite clear that the current fertilizer shortage will slow the pace of the "green revolution" in some nations which rely heavily on imports. These, in terms of the HYV's, are principally in South Asia. And while it will hinder its progress, it is doubtful that it will, as some accounts have suggested, result in an abandonment of the HYV's. The HYV's are considered to do as well or better than traditional varieties in the absence of fertilizer. In addition, the HYV's characteristically show higher rates of response to limited applications of fertilizer than do the traditional varieties. Thus it may be that what little fertilizer is available will be used to the HYV's, unless it is bid away by other more profitable crops. But even if we see some stagnation in the "green revolution" due to short-run fertilizer shortages, a tremendous potential remains.

D. Plant Protection

Although fertilizer shortages have held central stage recently, there are reasons to think that chemical pesticides may soon prove to be the next weak link in the chain of technologies that make up the "green revolution". The problem stems from an increase in worldwide demand for pesticides (up about 25% in 1973/74 according to one estimate 67/) and a constant or slightly decreased level of production. This has led, as might be expected, to an increase in pesticide prices.

The LDC's are almost completely dependent on imports of pesticide chemicals. What passes for production in some countries is in reality just a process of blending or formulating imported feedstocks. Hence the LDC's are in an even more vulnerable position than in the case of fertilizer. They could face a particularly severe problem during the 1974/75 season. 68/

Insect and disease control is even now an important problem. A recent survey of 30 Asian villages in six countries where modern rice varieties have been well accepted revealed that "the farmers consider pest and diseases the most serious constraints to high yields for modern varieties." 69/

Just how much the HYV's may have added to insect and disease problem is not entirely clear. Some have said that the HYV's have increased susceptibility because of (1) the close genetic interrelationships of the varieties, and (2) the fact that associated water control and fertilization practices encourage relatively lush (though dwarfed) growth. They also suggest that the HYV seldom enjoys the resistance which the traditional variety has acquired over the course of many years of local adaptation.

To some extent these concerns are very real, although in some cases they may be less well founded than they were a few years ago. We have been fortunate to date in having only a few and relatively limited problems uniquely due to the HYV's--despite the fact that farmers probably applied even less of the recommended levels of insecticides and pesticides than they have in the case of fertilizer. 70/

This may be pure luck. The HYV wheats introduced in South Asia happened to have good levels of resistance to local diseases. Over time the original HYV's have been increasingly crossed with local varieties in order to increase their suitability to local conditions. Insect and disease resistance have been major considerations in this process. Also the newer varieties from CIMMYT and IRRI have increasingly incorperated resistance. The changes that have been made in the IRRI rice varieties are are outlined in Table 3 (IR-8 was the first IRRI variety released, IR-26 the most recent).

The relative overall importance of insects and diseases varies between wheat and rice. In the case of wheat, insects are relatively less of an overall problem than are diseases (though insects may be important in localized areas). It has often been said that the new wheat varieties are less resistant to disease than those being replaced. In regard to rust this is, according to Anderson of CIMMYT, "an outright fallacy". He notes that in many countries, including India, they were the first

Table 3 -- Resistance Ratings of IRRI Rice Varieties

Problem	IR-8	IR-5	IR-20	IR-22	IR-24	IR-26
Lodging	R[1/]	MR	MR	R	R	MR
Diseases						
Blast	MR	S	MR	S	S	MR
Bacterial blight	S	S	R	R	S	R
Bacterial leaf streak	S	MS	MR	MS	MR	MR
Grassy stunt	S	S	S	S	S	MR
Tungro	S	S	R	S	MR	R
Insects						
Green leafhopper	R	R	R	S	R	R
Brown planthopper	S	S	S	S	S	R
Stem borer	MS	S	MS	S	S	MR
Soil Problems						
Alkali injury	S	S	S	S	MR	MR
Salt injury	MR	MR	MR	S	MR	MR
Iron toxicity	S	S	R	MR	MR	R
Reduction products	MR	MS	MR	MR	MS	MR

1/ Key: R = Resistant
MR = Moderately resistant
MS = Moderately susceptible
S = Susceptible

Source: The IRRI Reporter, No. 4, 1973.

resistant varieties in commercial production. Elsewhere, the HYV's have shown move resistance to rusts than have local varieties. In the case of Septoria tritici, the first varieties released in the Mediterranean were more susceptible. However, among them were resistant ones which are currently being grown. 71/ For rice, insects (which also transmit diseases) are probably the major problem. Altogether, the primary HYV chemical need may be fungicides to use in seed treatment and insecticides to be used on rice (and maize). 72/

As in the case of fertilizer, there are many opportunities to increase the efficiency of use of insecticides and pesticides. They are new to many farmers and are undoubtedly (and inadvertantly) often used at the wrong time, in the wrong dosage, etc. Also research may produce new ways of applying chemicals. For instance, IRRI recently developed a way of replacing insecticide sprays with a paddy water root zone application of granular insecticide; the method is more effective than sprays because it acts as a systemic and one application is effective throughout the growth period. 73/

There are also potentials for control through biological means. Some insects might be controlled by the sterile male technique. New cropping systems rotations might break up the normal insect or disease life cycle. In one study at IRRI, corn planted alone had six times as many borers as corn in which peanuts had been planted. IITA has found that rotations of different types of crops has prevented significant increases in nematode populations. 74/

All of these techniques offer potential for the future, but for the short run significant quantities of chemicals may continue to be necessary for effective pest control.

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The "green revolution" package is obviously a fragile one. The four major inputs - seeds, water, fertilizer, and plant protection - are in turn prey to many factors. As one Indian farmer recently said: "with less fertilizer, less diesel oil, less electricity, we seem to be going back to the age of bullocks and Persian wheels." 75/ These are not conditions, should they become widespread, hardly favor a "green revolution". Time will tell how significant they become.

V. CONCLUDING REMARKS

The "green revolution" in wheat and rice production has made significant contributions to the food supply of the developing nations where it has taken root. It will continue to do so, subject to fluctuations in weather, where economic conditions are favorable and associated inputs available. There is, however, a strong prospect that in some Asian nations the pace of the "green revolution" will level out in the near future due to input shortages or high input prices. There is little that the LDC's can do about some of these energy-based factors in the short run, but there are others (such as seed quality and distribution) where there is much that could be accomplished.

It is difficult to make many prognoses about the green revolution because of the large number of complex variables involved. Moreover, each technology may have its own outside sphere of interrelationships. Any one of these factors or interrelationships can become a limiting factor. Like many complex technologies, the HYV package is capable of great accomplishments, but it is susceptible of being at least momentarily thrown off course by failures of small components or by seemingly unrelated chains of events.

Because of the many permutations and combinations that are possible in this chain of events, we will not even attempt to trace them all out. Instead we will note a few interrelationships among the input factors noted in the previous chapter.

One that may not be anticipated is the balance between seed quality and fertilization. We noted earlier that some farmers in India, attempting to save on expenses, have turned to cheaper poor seed. As a result, fields are "jagged with stalks of every height" and each acre "contains half a dozen different varieties"

> Because accurate calculations of fertilizer applications cannot be made for such a mixture, whole fields are either underfed or overfed - and production is expected to be off by 15 to 13% 76/

Similar problems could be found elsewhere. As fertilizer becomes increasingly scarce and expensive, the results of such malpractices may be expected to multiply in seriousness.

Fertilizer usage by the plant is dependent to some extent on the amount of water available. Within certain ranges, the more water that is available, the more fertilizer the plant will be able to utilize. They are complementary factors. Hence in areas where water supply is limited there may be a relatively close correlation between additional supplies of water and additional use of fertilizer. (The correlation may not be evident where water is adequate for most normal levels of fertilizer use or the value of water in speeding fertilizer uptake is not well known). Hence it may be that in areas where fertilizer use is below recommended levels, the real culprit may be a relative lack of water. And lack of water may be in turn due to a shortage of energy to run the pumps. Desai noted this in India in late 1973: "...due to power shortage and difficulties in obtaining diesel oil there was a widespread shortage of irrigation water, and low use of fertilizers." 77/

The relationship is not normally considered reciprocal; fertilizer cannot usually substitute for water at low levels of water availability. Yet studies on upland rice by IRRI have shown that nitrogen applications combined with weed control sharply reduced the effect of drought on yields. 78/

It is necessary to separate out the individual effects of weed control and nitrogen applications, but perhaps there are situations where natural nutrient levels are so low that fertilizer applications would be of value even in the absence of what might be considered adequate moisture. In any case, both low nutrient and water levels mean reduced growth. 79/

There are also relations between these and other factors. As noted earlier, except for water the dry late winter period presents more favorable growing conditions in some portions of Asia, such as the Philippines, than does the wet season. Hence where irrigation water is adequate in the dry season, nitrogen fertilizer applications may show a higher response than during the wet season. Disease problems are also less. In India it has been observed that the most violent fluctuations in production stem from droughts and floods in the kharif or wet season. Hence increased emphasis is being placed on expanding grain production during the rabi or dry season. 80/ This step in turn however, would place more emphasis on the need to expand irrigation. Everything depends, it seems, on something else.

The fact that inputs have been used at relatively low levels in the past, however, provides both concern and hope for the future. Concern in that if past conditions didn't favor full use of the package, the future may not be more favorable. Hope in that if it is ever possible to get the whole package together, there is still a tremendous untapped yield potential.

All of this suggests that the "green revolution" will take considerable attention on many fronts by governments if it is to realize its very considerable potential. It has never been otherwise. But the current problems with the associated inputs, especially as related to energy, make the task even more complicated. Still, there are ways of making more efficient combinations of limited existing resources. These need considerable further attention.

VI. REFERENCES AND NOTES

Chapter I

1/ The course of the green revolution in Mexico has been examined in detail by William I. Jones and is reported in summary form in Dana G. Dalrymple and William I. Jones, "Evaluating the Green Revolution," presented at the joint meeting of the American Association of Science and the Consejo National de Ciencia y Technologia, Mexico City, June 1973, pp. 15-31.

2/ Ibid. A detailed listing of other studies is provided in Dana G. Dalrymple, Development and Spread of High Yielding Varieties of Wheat and Rice in the Less Developed Nations, U.S. Department of Agriculture, Economic Research Service, Foreign Agricultural Economic Report No. 95, June 1974, p. 2, fn. 2, In addition, the following articles by Robert E. Evenson should be noted: (with Y. Kisler) "Research and Productivity in Wheat and Maize," Journal of Political Economy, November/December 1973, pp. 1309-1329; "International Diffusion of Agrarian Technology," Journal of Economic History, March 1974, pp. 51-73; "The Green Revolution in Recent Development Experience," American Journal of Agricultural Economics, May 1974, pp. 387-394. Evenson has several further papers in draft form.

Chapter II

3/ This section is principally based on Dana G. Dalrymple, Technological Change in Agriculture: Effects and Implications for the Developing Nations, U.S. Department of Agriculture, Foreign Agricultural Service, April 1969, pp. 1-32.

4/ M.K. Lowdermilk, "Diffusion of Dwarf Wheat Production Technology in Pakistan's Punjab," Cornell University, Department of Agricultural Economics, Ph.D. Dissertation, May 1972, p. 335.

5/ Evenson, op. cit. (May 1974), p. 389.

6/ In at least some cases, however, the HYV's contribute to risk minimization because of their shorter growing season. Atkinson has pointed out to me that the HYV's reduce risk because they mature before the late fall dry weather in the Philippines.

7/ Barbara Harriss, "Innovation Adoption in India Agriculture - the High Yielding Varieties Programme," Modern Asian Studies, January 1972, p. 97.

8/ Harriss (op. cit.) makes use of the S-shaped curve for the inputs but mistakenly scatters the inputs along the same curve.

9/ That is, where irrigation water is available, there can be some flexibility in the timing and amount applied -- especially if tubewells are utilized. (Canal water, contrary to popular opinion, is often not available in the quantities or at the time desired.) In south Asia, farmers with tubewells commonly sell water to their neighbors.

10/ M. Lipton, as cited by Harriss (op. cit.).

Chapter III

11/ This point is discussed in lfurther detail for rice in Dalrymple, op. cit. (1974), pp. 5, 6, fn. 16.

12/ I have discussed multiple cropping in detail elsewhere. See Dana G. Dalrymple, Survey of Multiple Cropping in the Less Developed Nations, U.S. Department of Agriculture, Economic Research Service. Foreign Agricultural Economic Report No. 91, October 1971, pp. 30-31.

13/ Ian R. Wills, "Projections of Effects of Modern Inputs on Agricultural Income and Employment in a Community Development Block, Uttar Pradesh, India," American Journal of Agricultural Economics, August 1972, p. 458.

14/ The FAS estimates of total wheat area, yield, and production in Nepal are open to serious question in the light of recent estimates received from US/AID, Kabul; South Vietnam has been left out because of the influence of the war. For the record, Nepal showed a substantial increase in yield; Vietnam remained about the same.

15/ Adding the individual area and yield proportions does not usually equal the production proportion because of the different bases. Alternately, one could introduce a third residual percentage to take up the difference. Since the whole process may not be mathematically sound anyway, I stayed with the simpler process.

16/ Based on statistics compiled by John Parker, ERS, USDA.

17/ Within Ludhiana District of the Punjab, the growth in wheat yields preceeded widespread use of the current HYV's, beginning to climb sharply in 1963/64. This corresponded with a jump in nitrogenous and phosphatic fertilizer use and in the number of tubewells installed. (Based on data compiled by Arthur Dommen of the University of Maryland.)

18/ Malaysia was not included on the chart simply because its yield levels averaged above the upper bound. It showed no particular trend from 1960 to 1967, but then moved up substantially in 1968 and 1969. More moderate increases were registered in 1971 and 1973. Changes in accounting and reporting systems may have influenced some of the Philippine data.

19/ Sheldon K. Tsu, High-Yielding Varieties of Wheat in Developing Nations, U.S. Department of Agriculture, ERS - Foreign 322, September 1971, 40 pp.

20/ Based on statistics compiled by Parker, op. cit.

21/ Kenneth Murray, "India's Wheat Harvest to Fall Below Last Year's Supply Tight", Foreign Agriculture, May 13, 1974, p. 3. Murray also suggests two other factors:
- farmer uncertainly concerning the government's wheat policy (the grain trade was nationalized during 1973/74).
- diversion of some wheat area to other crops which were not monopoly controlled.

22/ L.J. Atkinson and David Kunkel, "HYV in the Philippines: Progress of the Seed-Fertilizer Revolution", U.S. Department of Agriculture, Economic Research Service, Foreign Development Division, unpublished manuscript, June 26, 1974.

23/ These estimates were subsequently used by an economist at the World Bank in making a rough assessment of the increase in output resulting from the HYV's (Agriculture: Sector Working Paper, World Bank, June 1972, p. 8). In making this assumption I presumed that the HYV's would be raised on the better irrigated land; therefore the ratio is not completely deflated.

24/ In the case of wheat, the countries cited have made extensive use of irrigation. A preliminary review of the data for dryland wheat production in North Africa and the Near East does not yet show a clear pattern of yield increase. This may be because of the still relatively low levels of adoption, but may also reflect (1) the impact of lower water levels and of variations in rainfall, and (2) the fact that the traditional varieties in some of the North African nations really are improved varieties that were introduced over the 20th century and which in some cases carry similar characteristics and ancestry with the Mexican varieties. Further detail on the latter point is provided in Dalrymple, op. cit. (1974), pp. 9-15.

25/ Atkinson and Kunkel, op. cit.

26/ Exploratory work in assessing the impact of the HYV's on production has been done by Evenson, and is cited in fn. 2. See particularly his article in the May issue of the American Journal of Agricultural Economics.

Chapter IV

27/ "Preliminary Assessment of the World Food Situation, Present and Future", FAO, April 1974, p. 68.

28/ Richard Critchfield, "India: The Lost Years", The New Republic, June 15, 1974.

29/ Andrew Pearse, "Summary of Conclusions; The Social and Economic Implications of the Larger-Scale Introduction of High-Yielding Varieties of Foodgrain", United Nations Research Institute for Social Development, Geneva, March 1974, p. 30. ("Draft paper not for quotation.")

30/ Surgit S. Sidhu, "Economics of Technical Change in Wheat Production in the India Punjab", American Journal of Agricultural Economics, May 1974, p. 223, fn. 1.

31/ Lewis M. Simons, "Fading of India's Green Revolution", Washington Post, May 5, 1974.

32/ Ibid. Citing Dr. Khem Singh Gill, head of the Plant Breeding Department of Punjab Agricultural University.

33/ Except as noted, the opening paragraphs of this section were based on Dalrymple, op. cit. (1974), pp. 6-7, and Dalrymple, op. cit. (1971), pp. 30-31.

34/ Principally in the warmer southern part of India, especially Tamil Nadu. Rice is not a winter crop in the cooler northern states.

35/ R. B. Reidinger and J. B. Parker, "Irrigation May be Answer to India's Urgent Food Needs", Foreign Agriculture, March 25, 1974 p. 10, A Study of the Contribution of Private Tubewells in the Development of the Water Potential in West Pakistan, West Pakistan University of Engineering and Technology and Lahore, June 1970, pp. 33-66; and F. Kahnert et al., Agriculture and Related Industries in Pakistan, OECD, Development Center 1970, p. 113.

36/ A Study of ..., op. cit.; Survey Report on Economics of Tubewell Irrigation in Selected Districts of the Punjab, Government of Pakistan, Food and Agriculture Division, Planning Unit, April 1972, p. 15.

37/ A Study of ..., op. cit.

38/ V. P. Shukla, "Well Irrigation - Its Costs and Benefits in Jabalpur District of Madhya Pradesh", Indian Journal of Agricultural Economics, Oct.-Dec. 1973, p. 235; Edwin Clark and Mohammad Ghaffar, An Analysis of Private Tubewell Costs, Pakistan Institute for Development Economics, Research Report No. 79, March 1969, pp. 60, 61.

39/ Simmons, op. cit.

40/ Takashi Oka, "Need of the Hungry", The Christian Science Monitor, June 20, 1974.

41/ For example, under land reform regulations passed in 1973, no individual farmer in the Punjab of India may own more than 18 acres of irrigated farmland, whereas they may have 54 acres of dryland. As a result it is reported that "many farmers have removed their diesel or electric pumps from tubewells in order to prove to government agents that certain fields are not irrigated and therefore their owners are entitled to a higher ceiling" (Simmons, op. cit.).

42/ Based largely on material provided in: R.G. Anderson, "A Second Look at the Green Revolution", Klink Lecture Series of the Agricultural Institute of Canada, Winter 1974; and a memo by Guy Baird, AID/TAB/AGR.

43/ Estimate provided by R. G. Anderson, CIMMYT.

44/ This is not to say, however, that the HYV's are inferior to traditional varieties in drier areas with poorer seed bed preparation.

45/ Based on Dalrymple, op. cit. (1974), notes by Baird, and comments by Anderson and Winkelmann.

46/ During the decade of the 1960's, fertilizer consumption in the LDC's expanded at an annual rate of 14.0 percent per year compared to a rate of 7.5 percent in the DC's (Raymond Ewell, "Fertilizer Use Throughout the World", Chemtech, September 1972). More recent consumption data are presented by Ewell in a recent paper on "Population Growth, Grain Production, and Fertilizer Consumption," May 1974, Figure 6.

47/ Based on data compiled from the Annual Fertilizer Review, 1972, FAO, pp. 48-49.

48/ R. B. Reidinger, "World Fertilizer Shortage Could Ease by Late 1975", Foreign Agriculture, January 28, 1974, p. 4.

49/ Cited by John B. Parker, New Technology in India's Agriculture and Outlook for Grain Production, ERS, F-341, June 1972, p. 19. Based on data compiled by G. M. Desai, Growth of Fertilizer Use in Indian Agriculture - Past Trends and Future Demand, Cornell University, Department of Agricultural Economics, July 1969, pp. 148-155.

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54/ Lowdermilk, op. cit., pp. 339, 342, 343.

55/ Atkinson and Kunkel, op. cit. (1973), pp. 1, 3, 4, 9, 10.

56/ W. W. Thamm, Introduction and Effects of High-Yielding Varieties of Rice in the Philippines, FAO, 1971, p. 31.

57/ Refugio I. Rochin, "A Study of Bangladesh Farmers' Experiences with IR-20 Rice Variety and Complementary Production Inputs", The Bangladesh Economic Review, January 1973, pp. 85, 86.

58/ Lowdermilk, op. cit., pp. 397, 399; Rochin, op. cit., p. 85.

59/ Research Highlights for 1973, The International Rice Research Institute, 1974, p. 35.

60/ "Modern Varieties Without Fertilizer", The IRRI Reporter, No. 3, 1973, p. 4.

61/ As summarized by C. Peter Timmer, "The Demand for Fertilizer in Developing Countries", Stanford University, Food Research Institute, unpublished manuscript, April 1974, pp. 9-20. Also, D.W. Larson and J. S. Cibantos, The Demand for Fertilizer in Southern Brazil 1948-1971, Ohio State, Department of Agricultural Economics, ESO 188, April 1974, pp. 17-18.

62/ "Fertilizer Shortage Threatens Famine in East Asia", Baltimore Sun, December 3, 1973. As of June 1974, however, the subsidies were still in effect (Atkinson).

63/ "SCU - A Time Pill for Plants", War on Hunger, January 1973.

64/ Trevor Drieberg, "The Lessons of the Drought", CERES, March - April 1974 p. 17.

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66/ See, for example, David Brand, "Man's Best Friend May be A Bacterium Called the Rhizobium", The Wall Street Journal, February 7, 1974; Jean L. Marx, "Nitrogen Fixation: Research Efforts Intensify", Science, July 12, 1974, pp. 132-136.

67/ W. R. Furtick, "The Pesticide Problem", FAO, May 24, 1974, 4 pp. (Furtick is chief of the Plant Protection Service for FAO. His notes were appended to an internal document and probably shoud not be cited.)

68/ Ibid.

69/ Research Highlights ..., op. cit., p. 43.

70/ The relatively low levels of fertilizer application, on the other hand, may have resulted in less lush growth and a greater susceptibility to pest problems.

71/ Anderson, op. cit., pp. 25, 26, 32.

72/ Furtick, op. cit.

73/ Notes by Guy Baird, AID/TAB/AGR; Research Highlights..., op. cit., p. 31.

74/ Ibid., p. 51.

75/ Oka, op. cit.

Chapter V

76/ Simmons, op. cit.

77/ Gunvant M. Desai, "Rapporteurs' Report on Agricultural Input Supply Systems Including Marketing", Indian Journal of Agricultural Economics, October-December 1973, p. 165.

78/ Notes by Guy Baird, AID/TAB/AGR.

79/ As the plant is starved, as we noted earlier, so also are some of the insect and disease organisms that infect it. So one slightly beneficial effects of the current energy shortage could be that some pest problems might not be as severe as they would be with the presence of adequate moisture and fertility (unless, of course, pesticide use is reduced even more than water or fertilizer use). The other side of this situation is that water supply and fertilization are improved, increased attention will have to be given to pest control.

80/ Drieberg, op. cit.