INNOVATIONS AND RESEARCH IN AGRICULTURAL DEVELOPMENT

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The world food problem, the ability of the Earth to support its inhabitants, has been recognized since Malthus wrote in 1798 his Essay on the Principle of Population. The problem has become more acute in the 20th century, particularly after the Second World War, when widespread medical services enabled world population to grow at an annual rate of 2 percent, from 2,500 millions in 1950 to 3,723 in 1970. Continuing at the same rate the world's population will double every 35 years. However, food production has expanded in the last two decades even faster and, for the time being at least, widespread hunger has been averted.

Viewed globally, increased food output is the consequence of intensification of agricultural production practices in most countries of the world. This intensification of agricultural production is not a new phenomenon. The gradual shift in old civilizations, in reaction to growing population density, from hunting and grazing through slash-and-burn systems to carefully cultivated and often irrigated multiple crop fields is a manisfestation of this general intensification process (Boserup 1965). These shifts required the discovery or the adoption of new technologies, methods of production, crops or varieties. The new element in the modern development on these historical trends is the prominent place occupied by scientific research in creating the new technologies both for agriculture of the developed and of the developing countries.

+ Also presented at the XX International Meeting of the Institute of Management Sciences, Tel Aviv, June 1973.

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Ehud Gelb was a most valuable research assistant.

The paper is divided into three main sections. The first surveys recent developments in food production, the second discusses agricultural research and its contribution to productivity. The third, the concluding remarks, brings forward some implications of the modern developments.

Food Production

Three aspects of the recent development in food production are presented in this section at three different levels of aggregation: Total food production, intensification in field-crops production, wheat yields in five representative countries.

Figure 1 summarises total and per-capita production data from 1954 to 1971. World-wide food production grew at an average annual rate of 2.8 percent. Population growth was 2.0 percent per annum and thus per-capita food production expanded at an average annual rate of 0.8 percent. (It should perhaps be added that per-capita food production is only a crude indicator of the food situation, see Poleman and Freebairn 1973.)

Over that period production expanded in all six regions in Figure 1. Per capita production was at worst constant--in Africa--and at best grew at 2.2 percent per annum in East Europe. Market forces and public regulations have limited further expansion of food supply in the west and prevented agriculture in the developed countries from reaching its production potential.

The increasing production of food is the consequence of a world-wide process of expansion of arable land and a continuing intensification of agriculture. One of the main components of this process is the spread of the use of fertilizers following substantial reductions in their prices due to technological improvements in the chemical industry (Sahota 1968). Between 1950 and 1970 fertilizers consumption in the world grew five folds at an average rate of 8.5 percent per annum and it increased much more than food production in all six regions. (Figure 1). Other, less documented aspects of the intensification process are expanded irrigation facilities, multiple-cropping, better varieties and heavier inputs of mechanical power: human labor, animals or machines.

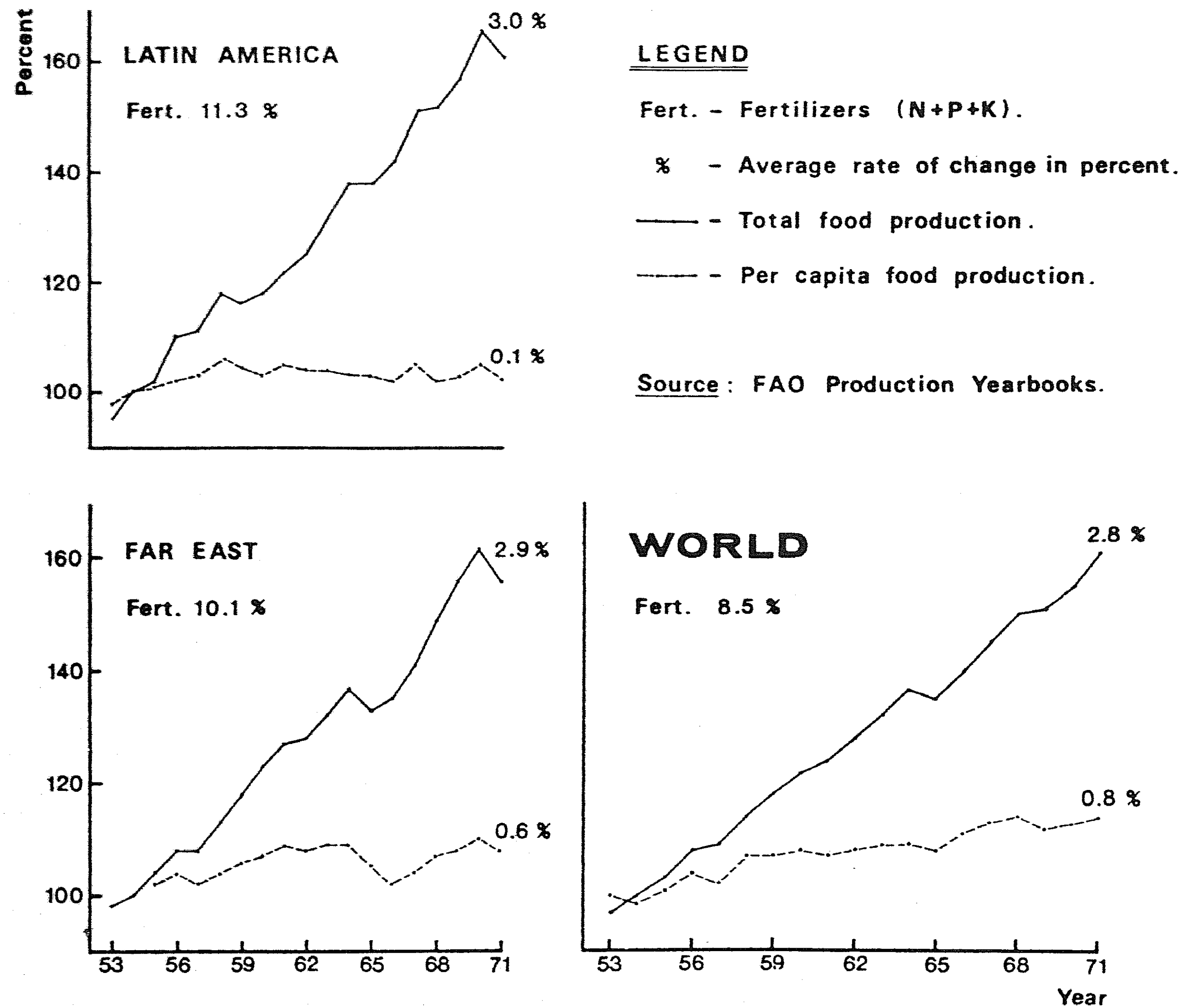

Fig.1A: Food Production Indices. Source: FAO Production Yearbook

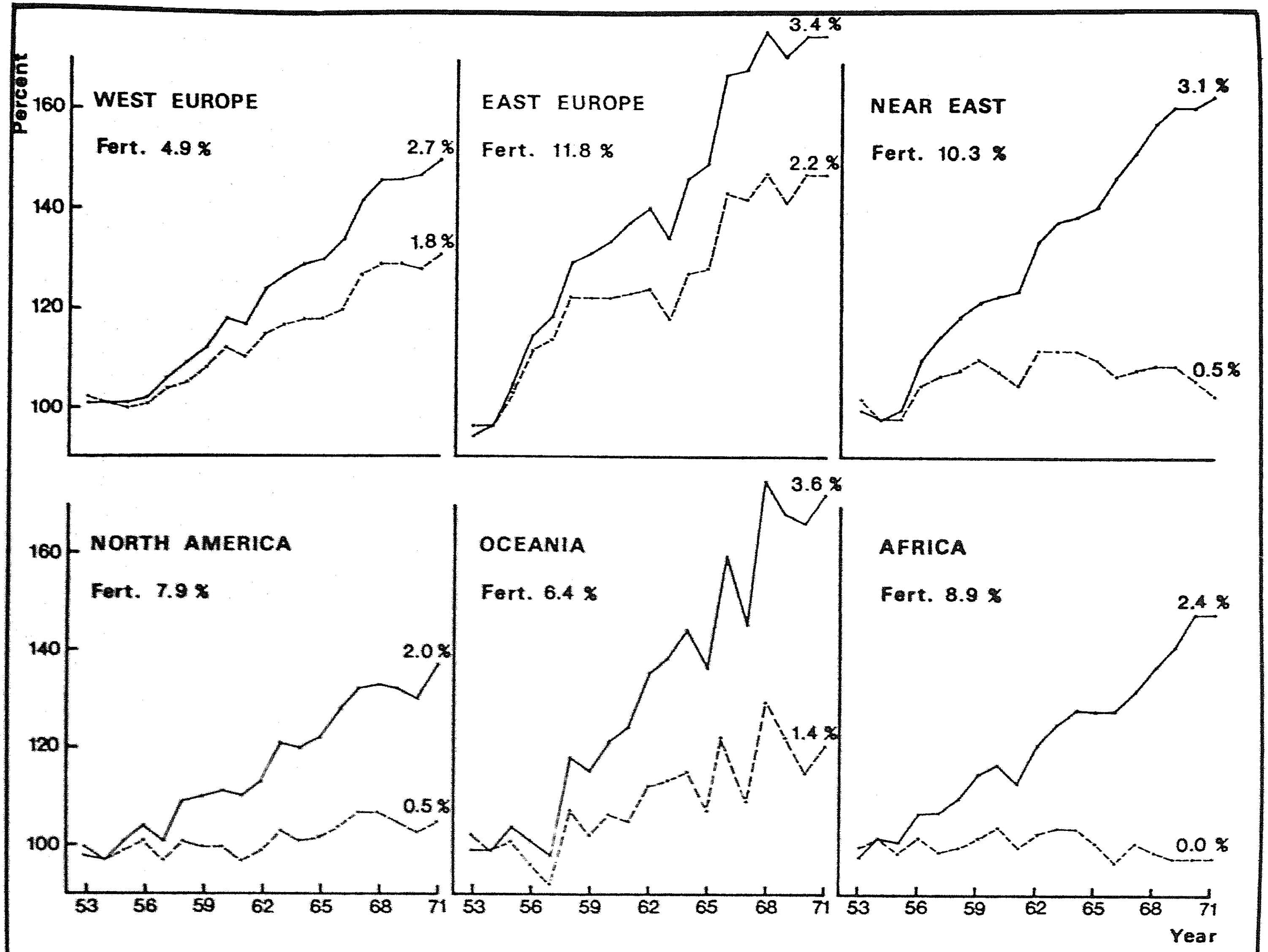

Fig. 1B: Food Production Indices. Source: FAO Production Yearbook

A more detailed analysis of the intensification process of agricultural production is presented in Table 1, in which growth of grain production is expressed as the sum of the contribution of increased area and of increased yields. Over the period 1950-71, world production grew at 2.5 percent per annum, area at 1.5 and yield at 1.0 percent per annum. World wide, the rate of increase of yield accelerated over this period: the average for the whole period was 1.0 percent, yield increase was 1.7 percent for the shorter 1959-71 sub-period and 2.9 percent for the last sub-period of 1965-71. Area planted to field crops grew, on the other hand, at a decelerating rate. Consequently, the importance of yield increases grew with time. Yield growth contributed 40 percent of production expansion for the whole period and 80 percent in the last sub-period of 1965-71.

As in the world as a whole, in most regions in Table 1 yield changes increased in their contribution to production. Exceptions are Europe and North America, but these were, already at the beginning of the period, exceptionally high yield-growing regions.

Figure 2 depicts wheat yields per unit of land in 5 countries from the beginning of the century. It is interesting to note that the differences between the yield levels of Japan, U.S. and India were quite small at the beginning of the period. But Japanese yields were already increasing in 1900, American wheat yields, like the European's, did not start their upswing until the mid-1930's. Indian yields were completely stagnant until the mid-1960's when the introduction of new Mexican wheat varieties ushered in the Green Revolution.

Agricultural Research

The development of the high yielding wheat varieties in Mexico (as well as of rice varieties in the Philippines, see Athwal 1971) is an example of the potential contribution of modern agricultural research to the intensification process and increased productivity. The main feature of these new varieties is their small size ("dwarfiness") and strong straw. As such they do not lodge, and respond effectively to fertilizers and irrigation. Small size wheat varieties were developed in Japan, where heavy manuring was widespread, before the Second World War, and these types supplied the genetic stock for the Rockefeller Program in Mexico.

Mexican wheat varieties are grown now on some 20 million hectares in Mexico, North Africa, the Middle East, Pakistan and India. This is an example of the special characteristics, often stressed by economists, of knowledge in production--it is hard to produce but almost costlessly transferred. In this case knowledge is transferred "embodied" in improved seeds. However, not all knowledge is readily transferrable. Meyren (1969) attributes the success of the wheat improvement program in Mexico to the facts that (a) wheat is locality insensitive, so the same variety can be grown successfully all over the country; and (b) wheat seeds can be propagated by the farmers and improved seeds thus diffuse from one farmer to another. Maize, on the other hand, is sensitive to climatic conditions and special verieties had to be bred for the various regions of Mexico. Also, hybrid maize seeds have to be produced by professionals and the farmer has to purchase them each year anew.

Maize is but one example of the role played by local research in increasing agricultural productivity. In the remainder of this section we survey the available data on agricultural research and present several estimates of its effect.

Table 2 summarises recently collected data. The estimated world totals (excluding mainland China) are close to 60,000 scientists(man-year) employed in agricultural research and an annual expenditure of the order of magnitude of 1.1 billion U.S. dollars. Research is concentrated in the developed, cooler regions of the world. The less developed countries produce approximately 30% of the world's agricultural product (by value) but have only 17.3% of the scientists and 11.4% of the dollar expenditures. Most of the less developed countries purchase the services of the scientific manpower at lower costs than the developed countries--$12,290 and $20,010 per year, respectively.

Expenditure and scientific man-power are inputs into the agricultural research system. The output of the system is the new knowledge created or "borrowed" from other countries or disciplines.

Knowledge is intangible, as a proxy measure of its creation we took the numbers of scientific publications in the agricultural sciences. Publications were

Table 1 : Cereal Production - The Intensification Process

A. Average Rate of Change (percent per annum)

	1950 - 71			1959 - 71			1965 - 71		
	production	area	yield	production	area	yield	production	area	yield
Far East	-	-	-	2.9	1.3	1.6	4.8	1.7	3.1
Near East	1.9	0.6	0.3	2.8	1.6	1.2	2.2	1.1	1.1
Africa	4.6	3.1	1.5	4.9	2.9	2.0	3.9	0.4	3.5
Latin America	3.9	2.5	1.4	4.7	2.9	1.8	4.3	2.1	2.2
Oceania	5.8	4.9	0.9	4.4	4.3	0.1	3.7	2.3	1.4
Europe	3.1	-0.2	3.3	3.3	0	3.3	3.0	0	3.0
North America	2.2	-1.6	3.8	2.1	-1.2	3.3	1.1	-0.4	1.5
World	2.5	1.5	1.0	2.5	0.8	1.7	3.6	0.7	2.9

B. Share of Increase in Yield in Increased Production (percent)

	1950 - 71	1959 - 71	1965 - 71
Far East	-	55	64
Near East	15	42	50
Africa	32	41	89
Latin America	35	38	51
Oceania	16	2	37
Europe	106	100	100
North America	172	157	136
World	40	55	80

Source: FAO Production Yearbooks.

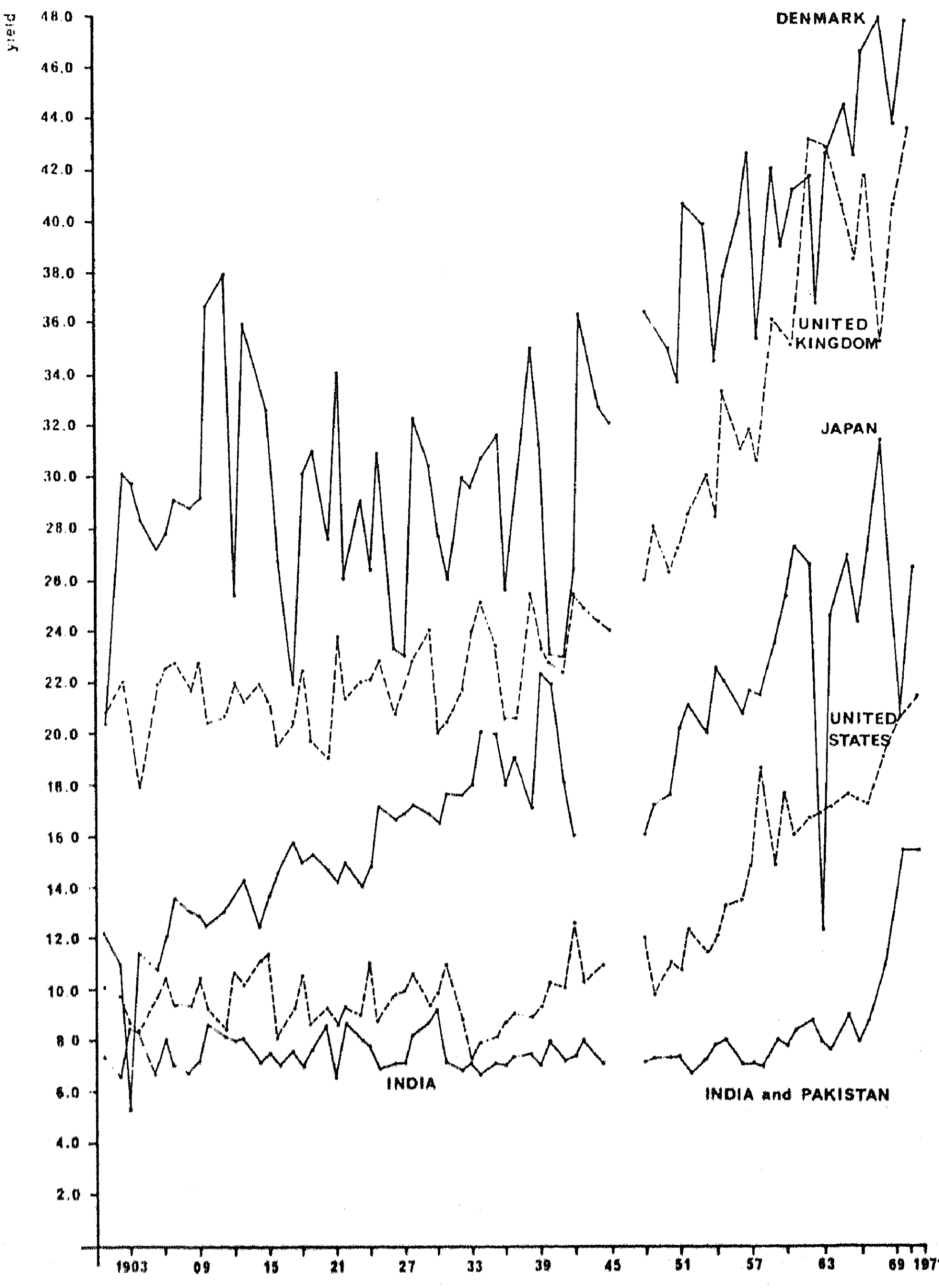

Fig. 2 ; WHEAT YIELDS (100 kg.per hectare) counted from abstracting journals and assigned to countries by the address of the first author. Only genuine scientific contributions are abstracted (instruction pamphlets, for example, are not), and this secures a floor to the quality of the counted publications.

The second part of Table 2 summarises publication data for the period 1962-68. We do not know what share of total publications in the agriculture sciences was covered by our counts. The calculations of expenditure and manpower input per publication should, therefore, be used only for inter-group comparisons.

Table 3 summarises budgetary data for the group of six International Agricultural Research Centers. These centers were established by the World Bank and the U.N. after the success of the Rockfeller Program in Mexico and of the International Rice Research Institute in the Philippines. The costs of the centers are covered by the international institutions, private foundations (Rockefeller, Ford, Kellogg) and the governments of the developed nations. As Table 2 reveals, an effort has been made to cover most climatic regions of agricultural production by the group of research centers.

Table 2: Agricultural Research - Summary of Basic Data*

	Developed Countries	Developing Countries	World
Manpower and Expenditure (annual data for 1965)			
Scientists (scientific man year)	49,262	10,292	59,560
Total expenditure (million US$)	985.7	126.6	1,112.3
Ratio to value of product (per cent)	.871	.259	.688
Publications (Averages 1962-68)			
Plant physiology	27,074	2,828	29,902
Crops	32,115	7,232	39,347
Livestock	31,579	2,478	34,057
Total Agriculture	63,694	9,710	73,404
Research expenditure per publication (US$)	108,300	91,300	106,051
Scientific man-year per publication	5.41	7.42	5.68

It is interesting to note the differences between the developed and the developing countries. The less developed countries spend close to 40% more scientific manpower input per publication, and though their budget per scientist is lower than in the developed countries, the cost per publication is only 15% less than in the developed countries. This can be a reflection of lower efficiency in research work.

After this short survey of research activity, we turn now to three estimates of the contribution of research to productivity: (a) an example of augmentation of the value of transferred knowledge through local research in Israel; (b) an econometric estimate of the contribution of research in wheat and maize; (c) the economic contribution of the Mexican wheat improvement program.

The Israeli experience in wheat improvement can exemplify the interrelationship of local research and imported knowledge.

* Source: Evenson, Kislev 1971.

Table 3: International Agricultural Research Centers

Institution	Area of Research	Approximate Budget for 1973 Thousands of US$
CIMMYT International Maize and Wheat Improvement Center, Mexico	Wheat Maize	5,400
IRRI International Rice Research Institute, Philippines	Rice	3,000
CIAT International Center for Tropical Agriculture, Colombia	Forage-beef in tropics, Cassava	4,200
IITA International Institute of Tropical Agriculture, Nigeria	Humid tropics agriculture, cowpeas, yams	5,500
CIP International Potato Center, Peru	Potatoes	1,400
ICRISAT International Crops Research Institute for the semi-arid, tropics, India	Grain, Sorghum, Millet, Pigeon peas, Chick peas	3,400
Total		22,900

Figure 3 summarises wheat variety replacements in Israel in the last two decades. The "old" varieties were selections from locally grown types; F.O. 8193 was introduced from North Africa. "Mexicans" were pre-dwarf Rockefeller-Program types introduced from Mexico. "Dwarfs" were the first generation of local selection from the dwarf Mexican types. "New" is a group of locally created varieties, combinations of Mexican and Israeli genetic material. Our preliminary estimates (prepared by Michael Hoffman) are that, compared with the standard F.O. 8193, yield increases due to the new varieties were

Mexican	5 percent
Dwarf	15 percent
New	30 percent

Thus local research augmented the effect of the imported knowledge and doubled the economic contribution of the advanced varieties.

The creation elsewhere of new high yielding varieties makes research aimed at transfer of knowledge a profitable economic activity. But local research can be quite effective even under less dramatic circumstances. In an inter-country study on productivity changes in wheat and maize (the study covered 64 wheat and 48 maize growing countries for the period 1948-1968) one estimate of the contribution of a unit of knowledge (a publication in the specific field) was as follows:

	Wheat	Maize
Direct contribution to home country	$19,341	7,575
Contribution to home country through transfer of knowledge	44,554	57,830
Contribution to others (who borrow)	2,390	1,038
Total contribution	$66,285	66,443

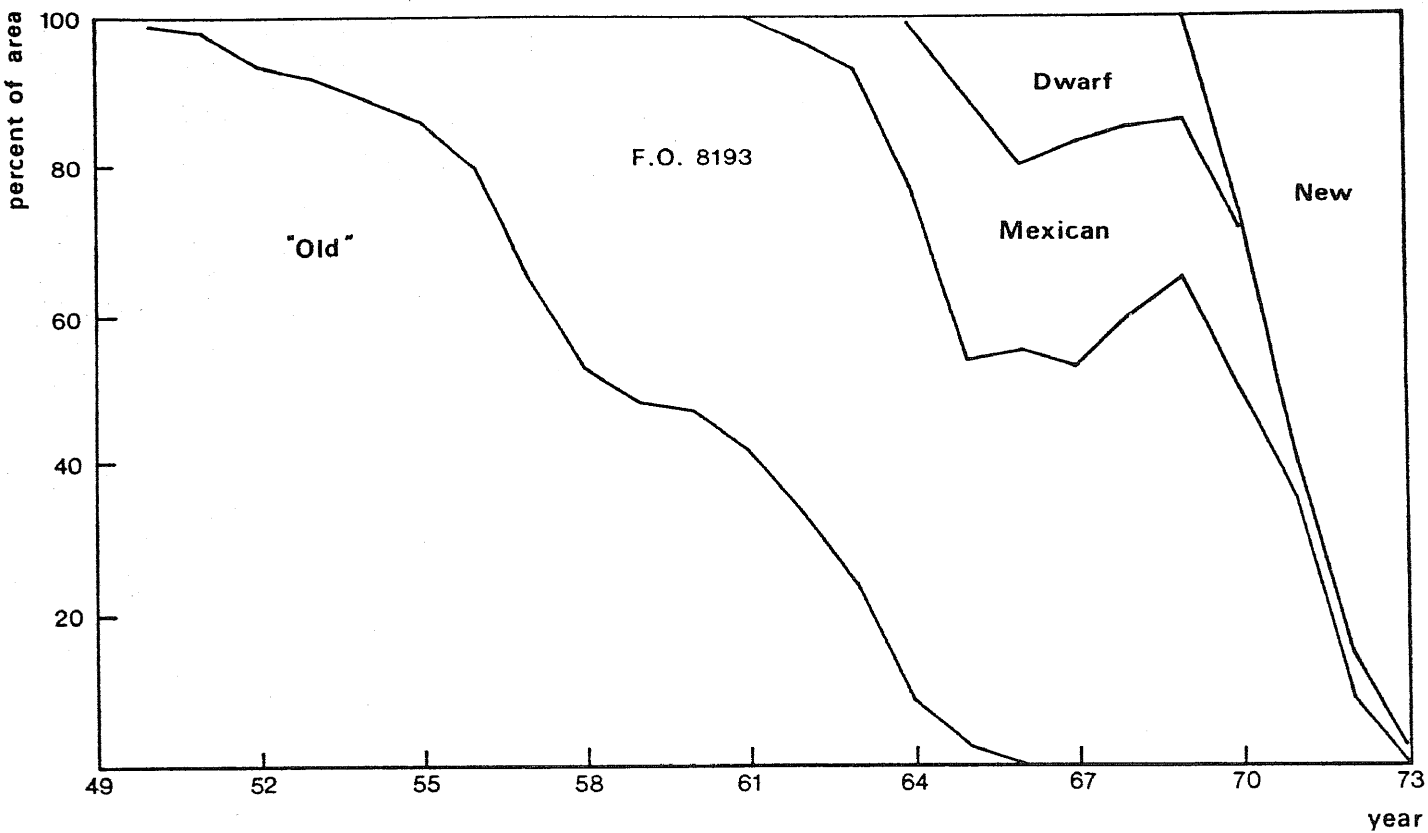

Fig. 3: Wheat Varieties Distribution

Given the paucity of data and the severe estimation problems, these findings should be taken as only indicative of general magnitudes. What they indicate is high rate of returns to research (the cost of a publication is of the order of magnitude of $100,000, see Table 2) and that, even before the Green Revolution, a major component of the contribution of research is in the transfer of knowledge.

Research is a risky venture, outcomes cannot be predicted in advance and it is possible that many of the projects undertaken by any institute will turn out to be complete failures. For research as a whole to be productive, the successful projects have to cover the cost of the failures.

We shall therefore try to examine whether the returns to the wheat improvements program can cover the cost of all six International Research Centers.

Today high yielding wheat varieties are planted on 20 million hectares. An under-estimate of the contribution of the work done in Mexico in wheat will be $140 million per year (100 kg. per hectare at $70 a ton). An over-estimate of the investment in the Mexican program is $167 million (total cost of the Rockefeller Program from 1943 to 1965 (Ardito-Barleta 1967) plus $5 million annually from 1966 to 1972, advanced at 10 percent per annum). This estimate includes work done on crops other than wheat and the benefits occuring before 1973 have not been deducted. Hence in less than two years the wheat program itself can cover all its cost and continue to cover all international research expenditure

If the probability of success of the new programs is anywhere near that of wheat,then the investment in the international research centers is indeed a sound one.

Two points should be added by way of qualification. (a) There is a flaw in the above calculations: to the extent that local research is highly productive and marginal benefit/cost ratio for investment in research is higher than unity, then the alternative cost of the research staff mobilized to the international centers is higher than what is reflected in their budgets. The magnitude of this effect is not known, but even if the real cost of the international research is twice the budgeted outlays, the benefits from the wheat program alone could, it seems, outweigh these costs. Also, the international research centers contribute to local research by training research personnel who go back to their countriés. (b) The benefit/cost calculations in the preceeding paragraph indicate that investment in the international centers is a sound one if the chances for success in other fields of study are similar to hose of wheat. Though research is risky and its results unpredictable, some factors that affect potential returns are known. For example, if research contributes equally to all units of production, say it increases yields by the same percentage in all farms, then the benefits are proportional to the volume of production of the improved crop. Wheat is, of course, a very important crop quantitatively, the impact of research other crops may be much smaller. Also, as the case of maize exemplifies, the prior probability of success is not the same in all crops.

Concluding Remarks

Optimism and pessimism about world food prospects are continuously alternating. Right now (Spring of 1973) with drought hitting South East Asia, the pendulum has swung to the pessimistic side. But, as the present survey indicates, there is reason for guarded optimism in the intermediate run (for the next 20 years), even if short-run prospects are disheartening. Any long-run predictions will be dangerous and clearly unfounded.

Food being a basic necessity, any increase in its supply is welcome. But the intensification process of agricultural production, particularly its faster phases such as those associated with the Green Revolution, may entail difficult adjustments in the rural sector (Griffin 1972). Basically, the new technologies have an unbiased effect--yield will increase in all farms alike, but the dynamics of technological changes favour the larger and wealthier farmer. The reason being that higher yields mean higher incomes and higher savings. The larger farmers can then be the first to invest in tube wells, tractors and modern inputs. To benefit fully from these new capital assets, enterpreneurial farmers may try to increase the areas of their farms. As yields rise, supply expands and prices decline, this may squeeze the small, often inefficient, farmer out of agriculture.

From the long run point of view, this is the economic process through which agriculture contributes labor to the expanding urban and industrial sector. But for the laborer who moves it makes a big difference whether he is drawn toward better prospects in the city or has to leave farming because of declining income in the countryside. Thus, while the majority of the population may enjoy higher incomes and larger diets, a great number of small peasants may pay a very high cost for these improvements. It is questionable whether the less developing countries have the ability or the will to institute efficient employment and welfare policies to mitigate these hardships.

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