Research and Productivity in Wheat in Israel

*by Yoav Kislev and Michael Hoffman**

The introduction of the new Green Revolution wheat varieties to Israel is reviewed and analysed. It was found that the first stage varieties (developed from local Mexican wheats) did not have a significant impact on yields in Israel. Dwarf varieties and new crosses bred in Israel from Mexican genetic material contributed significantly to yield increases. Returns to local research are estimated. Conclusions about the role of the International Research System are drawn.

Wheat is, in Israel, a dry-farming crop, grown in the rainy winter. Auxiliary irrigation of 150–200 mm[1] is applied to some of the fields, particularly in the drier South and in drought years. The crop is grown on large-scale mechanised farms—on intensive garden lands and family farms its area is limited to the minimum requirements of crop rotation (a 'soil drier').

Wheat occupied, in early 1950s, less than twenty per cent of the dry farming area in Israel. Today, it is the most important single crop planted on more than 55 per cent of the dry farming area. The expansion of wheat production is the outcome of substantial technical improvements: despite the area expansion—possibly on to comparatively inferior soils—average yield in the country grew by 70 kg per hectare annually (Figure 1).

Two interacting sources contributed to these increases in wheat yields: agrotechnical improvements and variety replacement. The most prominent of the agrotechnical improvements is the increased application of fertilisers—nitrogen input rose five folds in the last twenty years.[2] The introduction of new varieties enhanced the economic contribution of fertilisers and therefore their application; it also made auxiliary irrigation and disease control more profitable and expanded their usage. These expansion and intensification processes augmented further the contribution of research and extension activities in wheat.

Wheat research was conducted in Israel for many years, varieties were selected and improved and yields raised. However, the greatest boost to productivity followed the introduction of the Mexican, Green Revolution, varieties. This study is an attempt to analyse the process of the Green Revolution in Israel and to estimate the contribution of local research to this process.

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WHEAT VARIETY IMPROVEMENT

Several stages can be distinguished in the development of wheat varieties in Israel [*Ephrat, 1968*]. In the first stage, before the Second World War, superior strains were selected from local varieties, and tests of imported varieties were conducted. Strains selected had completely replaced, at least in the modern farming sector, the local varieties. Most successful of the imported varieties was Florence Aurore 8193 (imported in 1944). It had a high yield potential, strong straw, and was resistant to rust diseases. The Florence was the dominating variety in Israel from the mid 1950s to the end of the 1960s (see Figure 2, where varieties grown before the Florence are marked 'old').

A new stage in the development of wheat varieties began when the first results of the work of the Rockefeller Foundation in Mexico reached Israel. At first, the Rockefeller group concentrated on the selection and breeding of varieties from local (Mexican) genetic material. Particular attention was given to disease resistance. The first varieties of this stage in Mexico were imported in 1954 and grown commercially in the early 1960s ('Mexicans' in Figure 2). Their main advantage over the Florence was in rust resistance, and that the seeds did not fall out. Some of these varieties lost their resistance after two years in commercial fields.

The second stage of wheat breeding in Mexico was the development of high fertiliser responsive varieties. This is a case of 'induced innovation' [*Hayami and Ruttan, 1971*]. The traditional wheat varieties grown throughout the world were suitable for extensive cultivation practices [*Atwal, 1971*]. The rise in the demand for food and the reduction in the real cost of fertilisers [*Sahota, 1968*] created the need for high-yielding, fertiliser-responsive varieties. Such wheat varieties were developed in Japan already at the end of the nineteenth century and incorporated into the Mexican programme in its second stage.

The first dwarf varieties were imported from Mexico to Israel in 1960 and some of them were grown commercially, after a short propagation period, in 1962 ('Dwarf' in Figure 2).

Two additional stages in the development of wheat in Israel were the intensive selection of dwarf varieties specially suitable for local conditions, and the breeding of new varieties from local and imported dwarf genetic materials. The outcome of these stages—the 'new' varieties in Figure 2—today occupy more than 90 per cent of the wheat area in the country.

PRODUCTIVITY ESTIMATES

In this section we report the estimates of the contribution of several factors to productivity in wheat. The framework of the analysis was a multiple-regression equation with yield-per-hectare the dependent variable (Table 1). The emphasis was on the net variety effect allowing for the contribution of the other factors. The major modifications in agrotechnical practices during the sample period were variety turnover and increased utilisation of fertilisers and auxiliary irrigation. Other technical changes were comparatively minor and could not be identified in the study. However, often the better farmers or the better regions adopt the newly introduced varieties faster; also, promising varieties may be allotted the more fertile

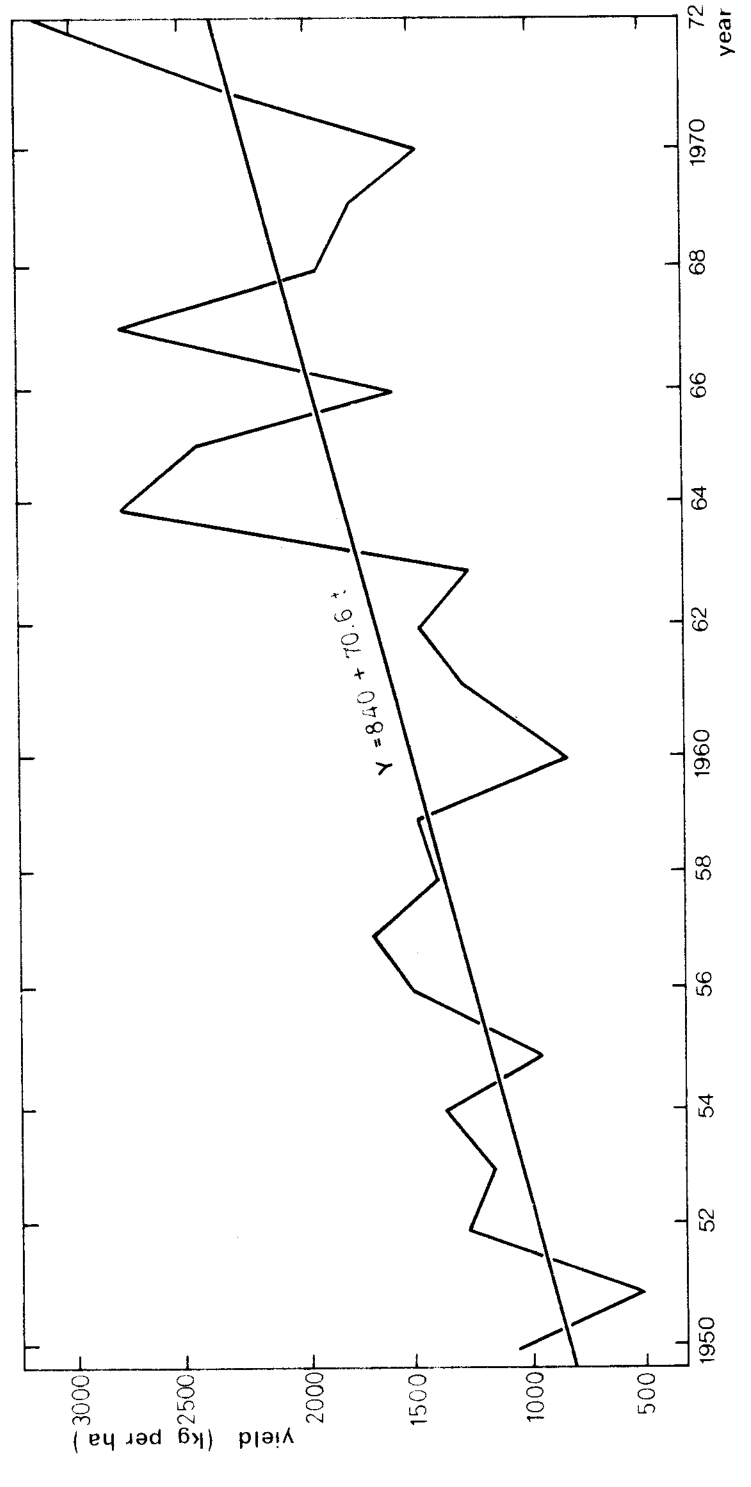

Figure 1: Wheat Yields, Annual Country Averages and the Regression Line

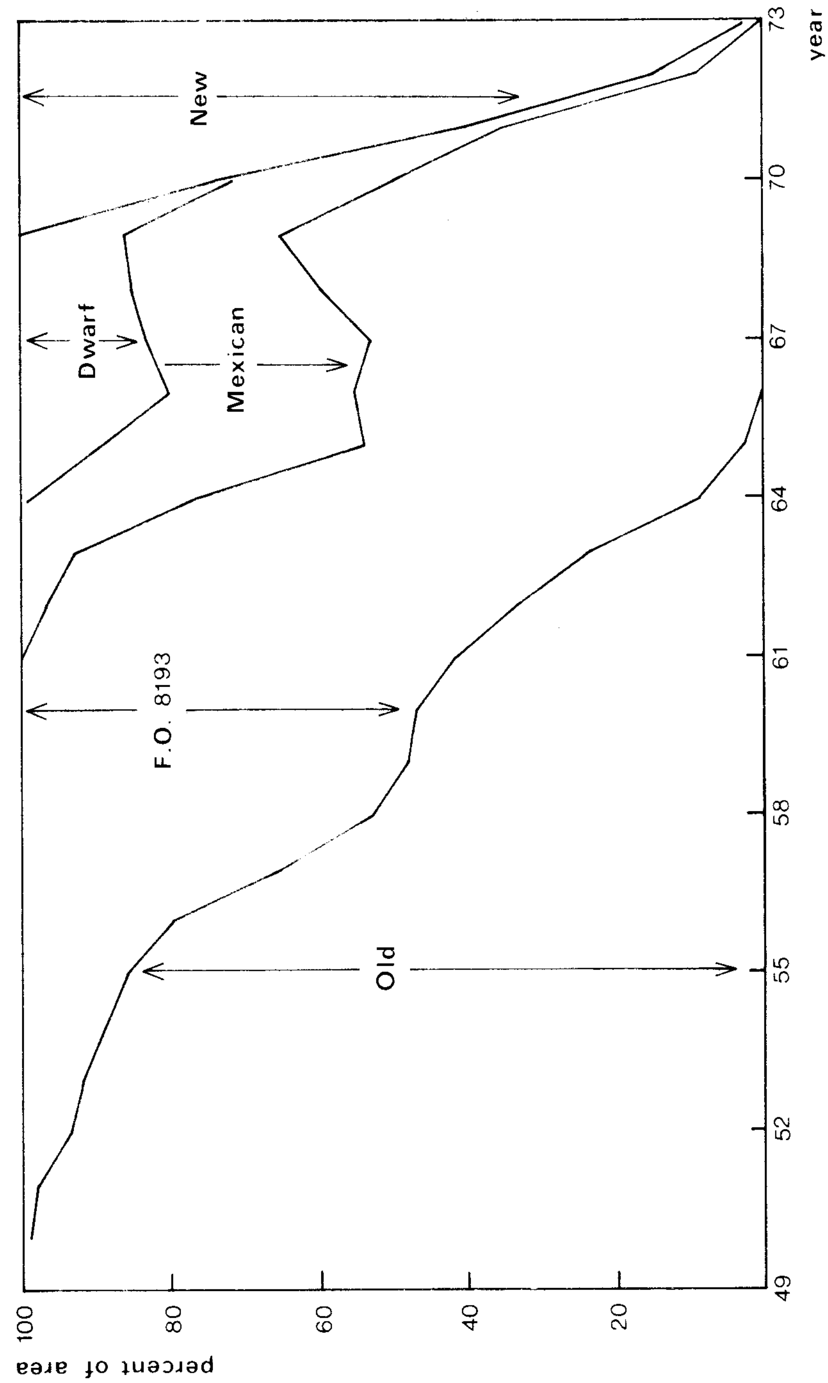

Figure 2: Wheat Varieties Turnover

plots on the farm. To prevent over-estimation of the variety effect, these last factors were also incorporated in the regressions.

The data came from a sample of dry farming enterprises in kibbutzim (collective villages). The sample covered eleven kibbutzim for the period of 1951–73; most data were, however, for the second half of the period. The kibbutzim included were those that kept records and were willing to co-operate. The typical observation was a wheat plot in a kibbutz in a certain year. The data collected included: variety, yield, fertilisers input, auxiliary irrigation, disease control, previous crops, and the management's estimate of the natural fertility of the plot. The total number of observations was 988, but not all were complete; 405 observations were from enterprises where data on auxiliary irrigation were recorded regularly, and 481 observations included information on fertiliser.

The varieties were classified into five groups (Figure 2): old, Florence, Mexican, dwarf, new (Mexican–Israeli crosses). The Florence served as the reference group, and the contributions of the other varieties were estimated relatively to this standard variety.[3]

The major findings are presented in Table 1. Estimates were carried out at the sample level and for each kibbutz separately. Estimates for a kibbutz in the northern part of the country and for a kibbutz in the south are presented in Table 1, as well as estimates carried out for the whole sample ('country sample' in the table). The regressions in the table are double-log, weighted by plot area.[4] The data are for the sub-sample with complete coverage of fertiliser application. The variables time, rain[5] and nitrogen application entered the regressions as quantitative (continuous) variables; others as qualitative (dummy) variables. Auxiliary irrigation was also represented by a qualitative variable (which was assigned the value one for an observation with auxiliary irrigation, and the value zero for an unirrigated plot) despite the fact that data on the quantity of irrigation water were available. The reason for this procedure was that the amount of auxiliary irrigation is negatively correlated with natural soil moisture, and that the major effect of the auxiliary irrigation (which is often given in standard amounts) is the mere fact of its application and at the right time.

Regression 1 in Table 1 is an estimate of yield increases with time. Yield, in the sample as a whole, increased at the rate of five per cent per annum; the rate was six per cent for the northern kibbutz and three per cent for the southern. These rates are estimates of the 'gross time effect'—including the effects of variety replacements and other technological improvements. The other estimates in Table 1 can be viewed as an attempt to separate the gross time effect into the contributing components.

Precipitations and auxiliary irrigation were added in Regression Group 2 and in Table 1. Precipitations do not contribute significantly to yields in the rainy North, where auxiliary irrigation is also only rarely practiced. In the drier South, however, the effects of rain and irrigation were significant, and with these two variables in the regressions, the net effect of the time variable becomes insignificant.

The complete model is estimated in Regression 3. The regression includes, for the northern farm, the complete set of qualitative variables (see notes to Table 1). The 'farm effect' (which stands for regional

TABLE 1

REGRESSION ESTIMATES OF PRODUCTIVITY FACTORS IN WHEAT

Regression	*1*			*2*			*3*		
Sample	*A kibbutz in the North*	*A kibbutz in the South*	*Country Sample*	*A kibbutz in the North*	*A kibbutz in the South*	*Country Sample*	*A kibbutz in the North*	*A kibbutz in the South*	*Country Sample*
R^2	·41	·02	·24	·42	·68	·51	·61	·78	·55
Intercept	5·14	4·81	5·42	3·90	−1·45	·72	4·38	−2·11	3·71
	(70·60)	(20·61)	(84·91)	(4·29)	(1·70)	(1·50)	(4·68)	(2·67)	(6·64)
Time	·06	·03	·05	·06	−·01	·03	·02	−·08	−·02
	(8·57)	(1·33)	(9·65)	(8·50)	(·98)	(4·45)	(1·29)	(3·67)	(1·64)
Rain				·20	1·13	·76	·10	1·23	·36
				(1·37)	(7·21)	(9·41)	(·66)	(8·43)	(5·09)
Auxiliary irrigation					1·13	·65	·07	·99	·46
					(10·92)	(12·94)	(·46)	(8·98)	(9·44)
Nitrogen							·21	·39	·21
							(1·71)	(4·32)	(2·70)
Varieties:									
Old							−·03	·14	−·43
							(·22)	(·29)	(3·78)
Mexican							·07	−·04	−·01
							(·78)	(·24)	(·18)
Dwarf							·25	−·11	·39
							(1·98)	(·54)	(5·67)
New							·27	·22	·49
							(2·09)	(1·77)	(7·66)
Minka									·17
									(·56)
Gabo								−·33	·09
								(1·86)	(·70)
Number of Observations	105	71	405	105	71	405	105	71	405

Notes The dependent variable: (log) average yield per plot in Kg per hectare.
A farm effect was included in the country sample regressions.
Sample period: A kibbutz in the North 1957–73
A kibbutz in the South 1961–73
Country sample 1960–73
In parenthesis—t values.
Regression 3 for the kibbutz in the North included also the following variables: previous crop (7 possibilities) and quality of plot (4 levels grouped by the management).

conditions, management, and other specific factors) was included in the regressions at the sample level. Here, unlike Regression 1, the time variable is insignificant and even negative in the South. A negative time coefficient can be a reflection of two factors: (a) With time, area expanded and wheat was planted on inferior soils. To some extent, at least, this factor was allowed for by including the plot effect in the regressions. (b) A negative time coefficient may be due to the loss of disease resistance in wheat varieties. If varieties were not replaced, and inputs were not augmented correspondingly, yields would have decreased with time.[6]

The contribution of rain and irrigation are large in the South and small in the North. The 'Production Elasticity' of rain in the South is 1·23; i.e., an increase of 10 per cent in the quantity of rain will increase yields there by 12·3 per cent, while in the North the rainfall coefficient is only 0·10.

TABLE 2
MARGINAL CONTRIBUTION OF PRODUCTIVITY FACTORS, CALCULATED FROM REGRESSION 3 IN TABLE 1 (KG PER HECTARE)

Variable	*Unit (quantitative variables)*	*A kibbutz in the North*	*A kibbutz in the South*	*Country Sample*
Time	Year	(60·0)	−130·4	−50·2
Rain	Mm rain	(·60)	7·9	2·4
Auxiliary irrigation	qualitative	(21·0)	2705·8	1455·6
Nitrogen	Kg Nitrogen	84·0	95·1	67·0
Varieties: Old	qualitative	(−90·0)	(211·9)	−903·6
Mexican	,,	(210·0)	(−5·2)	(25·1)
Dwarf	,,	(840·0)	(−228·0)	1204·8
New	,,	930·0	326·0	1581·3
Minca	,,			(476·9)
Gabo	,,		−782·4	(225·9)
Average Sample Yield (geometric)		3000	1630	2510

Note In parentheses—not significant at the 10 per cent level.

Table 2 calculates the marginal contributions of the factors affecting productivity. These values are calculated from the regression estimates of Table 1 (which are elasticities) for the sample geometric averages. For the kibbutz in the North, where yield increases (after allowance for variety effects and other factors) at 2 per cent per annum, this is an increase of 60 kg per hectare annually. Time effect in the South and for the sample as a whole is negative. One millimetre of rainfall adds 0·6 kg per hectare in the North, 7·9 in the South and 2·4 kg at the sample level.

Variety contribution is larger for the whole sample than for the individual kibbutz. By this estimate, yields of 'old' varieties are lower than that of the Florence by 900 kg per hectare, and the 'Mexicans' are only slightly better than the Florence. Yields of the 'dwarf' varieties exceed that of the Florence by 1,200 kg per hectare, and the 'new' varieties by 1,580 kg per hectare. The contribution of the Minka and Gabo varieties does not exceed those of the dwarf type (these varieties were, however, developed for specific local conditions).

Some of the differences in the estimates for the North and the South and the sample as a whole, could be expected, as, for example, the substantial differences in the marginal productivity of rainfall. It is also indicated from the estimates that the marginal contribution of the modern varieties is higher in the North, in the more fertile regions. But not all differences in the estimates can be explained at this stage. Some of these differences may be due to random deviations in estimates conducted at the single kibbutz level.

The sample is not stratified and representive, and it is possible that its estimates are biased. We shall return to this issue in the next section.

THE CONTRIBUTION OF DOMESTIC RESEARCH

Conceptually, the contribution of research can be estimated from a hypothetical experiment comparing agricultural production with research to production in its absence. Practically, such an experiment cannot be conducted. In this study, we assign to the research system the contribution of the new varieties to productivity: this contribution being net of the effects of other factors. This procedure calls for some justification.

Agricultural research was not confined to genetic breeding and selection of varieties. Research efforts were also devoted to agrotechnical problems, such as weed control, irrigation practices, and other aspects of agricultural production. The effect of these lines of research is reflected in our estimates in two ways: (a) Partly, this work enabled the successful adoption of the new varieties, and as such these should be considered as part of the breeding effort, breeding in the broader sense. (b) Partly, these studies are reflected in the time coefficient. If not for them, the coefficient would have been lower.

A crucial aspect of agricultural research is yield maintainance. There are indications that the Florence variety would have been subject to yield losses—perhaps because of the spread of new rust strains—if it had not been replaced. The varietal contributions in Tables 1 and 2 are calculated relatively to the Florence. If indeed the yields of this variety were due to fall, the contribution of the new varieties is underestimated. It should have been calculated as the yield difference comparative to the level Florence would have reached had it not been replaced.

A major input into domestic agricultural research is imported knowledge; brought in the form of scientific publications, exchange of scientists, data and equipment. In wheat, the knowledge is embodied in the Green Revolution varieties. An interesting issue is the division of the contribution of technical change to the part contributed by the local system and the part contributed by knowledge imported from outside. This question has one answer from the point of view of Israel, and another if viewed from a wider perspective.

From the Israeli point of view, the contribution, all of it, is local because the knowledge was imported free of charge. From the point of view of the Israeli decision maker who has to decide on the allocation of funds to research in the country, free knowledge is part of the environment in which the local research system is operating. The cost of producing this knowledge abroad should not have any effect on his decision.

There is, however, another question which is relevant from the Israeli research system point of view. This is the question of how much of the imported knowledge would have been brought in and applied in the field in the absence of the local research system, perhaps by the farmers themselves. Since, in the case of wheat, the new varieties were not merely imported, but were also subjected to severe selection procedures and later included in breeding programmes, we have assumed in our calculations that the contribution of the new varieties can be attributed completely to the research system. That is, we assume that no improved varieties would have been introduced without research. This possibly introduces an element of overestimation in the contribution of the local research system. There are countries that adopt high yielding varieties directly from foreign sources and not through a local research system. However, recent reports indicate disappointments with these varieties; disappointments due to loss of resistance to local diseases and inability to maintain the yield level under varying climatic conditions. A local research system, by breeding, selection and study of agronomic techniques, opens the way for successful adoption of imported varieties.

From the Israeli point of view, all the economic gains due to the new varieties are part of the contribution of the local research system. The international perspective is quite different. An upper bound to the contribution of the Rockefeller Programme in Mexico to wheat production in Israel is the economic gains attributable to the new varieties minus the cost of local research on selection and adoption of these varieties. In deciding on the level of its investment in research, an international agency which views as the benefit of that investment the productivity gains in all countries, will rightly use the above mentioned upper bound as a measure of the benefit realised in Israel. The sum total of such benefits in all countries constitutes the contribution of a research programme whose findings are subject to international transfer.

In the absence of a market in which the international research system charges a price for transferred knowledge, there does not exist a unique division of the contribution of the knowledge between the domestically created component and the borrowed and imported knowledge.

The case of the new wheat varieties is a particularly successful case. The Israeli scientists were fortunate to be able to draw on the success of their colleagues in Mexico in producing high yielding wheat types adaptable to a wide range of climatic conditions. In calculating the returns to research, the contribution of the successful development in wheat has, therefore, to be compared to the cost of research on a wider range, including less successful research efforts. Just as the returns to a lottery ticket should be calculated by comparing the prize to the cost of all tickets, not merely to the cost of the winning ticket. The returns will, therefore, be calculated below at three levels: to research in wheat, in dry farming, and in field crops.

The introduction of new technologies may sometimes modify significantly the farming systems, income distribution and resource allocation. This was not the case with the new wheat varieties. As Israel imports most of its grain, agriculture faces a completely elastic demand curve for grains, the economic contribution of the additional output can, therefore, be simply evaluated at the world price of wheat.[7]

As mentioned in the previous section, it is reasonable to suspect that our sample is not representative. This fact has two aspects: (a) Record-keeping wheat growers are usually better than others, and yields on their farms are probably higher than on other farms. This bias will be corrected by comparing sample yields to average yields in the country, and in calculating the economic benefits, allowing for the differences. (b) The distribution of wheat areas in the sample is not proportional to the distribution in the country. The share of the South in the sample, for example, is smaller than the corresponding share in the country. In an attempt to overcome this source of bias, the contribution of the new varieties in the country was calculated as a weighted average of the estimated contribution in the individual kibbutz, the weights being the share of the region in which the kibbutz is located in the country's wheat area. Alternatively, the returns to research were calculated from the country level estimates. The differences between the calculated contributions and returns for the two levels were small and insignificant. The results presented will be those based on the country sample estimates.

The date chosen as the zero point for the calculation of the returns is the year 1974. The returns were calculated to the wheat breeding 'project'. It was assumed that the project lasted from 1954—the year at which the first Mexican varieties were imported—until 1973. By assumption, the project was completed in 1973 with the new varieties occupying practically all the area sown to wheat.

The method used in calculating the returns was the following [*Griliches, 1958*]: it was taken that benefits realisation in the project started in 1965 with the introduction of the semi-dwarf varieties to commercial plots. In this way, the contribution of the first Mexican varieties is neglected since the estimates of their contribution were insignificant (Table 1). Annual benefit was calculated by multiplying the area sown to a variety by the yield differences between the variety (variety group) and the reference variety Florence Aurore 8193. Table 3 shows calculated annual benefits.

The sample estimates were corrected on two points:

(a) The rate of yield increases in the sample was 19 per cent higher than the country's average. The sample estimates of yield increases were, therefore, reduced by 19 per cent.

(b) Yield level in the sample was 44 per cent higher than the country's average. The yield of the Florence variety was reduced in the calculation to that extent (this correction is of minor importance since it affects only the correction for flour backing quality which is reflected in variety price differences).

A simple check indicates that the values in Table 3 are reasonable. Average country yield rose over the period 1963–1973 by 105 kg per hectare, per annum; applying this rate to the ten-year period and multiplying by the area sown to wheat in 1973, we find that the additional product due to these per-hectare yield increases was 67,481 tons. In the prices used in our calculations, the value of this addition was I£. 20,784,000, compared to I£. 15,164,000 in the table. Thus, by this rough estimate, variety turnover explains 3/4 of the difference between the actual 1973 wheat production in the country and the yield that would have been harvested on the 1973 area with 1963 per-hectare yield.

Table 4 calculates the returns to research. Line 1 in the table is the 1974 value of the economic contribution of Table 3. Capitalisation was carried out at two rates of discount: 5 and 10 per cent. Line 2 is the permanent flow equivalent of the stock value of line 1. At a discount rate of 5 per cent, for example, the flow equivalent of I£. 50,140 million is I£. 2,510 million annually.

TABLE 3

VALUE OF CONTRIBUTION OF DWARF AND NEW VARIETIES (THOUSAND OF I£ IN REAL PRICES)

	1965	*1966*	*1967*	*1968*	*1969*	*1970*	*1971*	*1972*	*1973*	*1974 predicted*
Dwarf	982	1,561	1,657	1,779	1,574	401				
New						3,897	8,065	12,493	15,164	17,431
Total	952	1,561	1,657	1,779	1,574	4,298	8,065	12,493	15,164	17,431

Notes Calculated for the Country Sample.
Prices are deflated by GNP price index, 1967–69 = 100.

TABLE 4

RETURNS TO RESEARCH (I£ MILLIONS I)

		rate of discount (r) 5 per cent	10 per cent
(1)	The contribution in Dwarf and New varieties in the period 1965–73.	50·14	57·25
(2)	The contribution as a permanent flow (2) = r (1)	2·51	5·73
(3)	Predicted future annual contribution	17·00	17·00
(4)	Annual outlay in wheat research (to maintain present yields).	1·00	1·00
(5)	Annual net contribution (5) = (2) + (3) − (4)	18·51	21·73
(6)	Research outlays in field crops 1954–73.	108·78	162·41
(7)	Returns to research in field crops		
	internal rate of return (per cent)	16	13
	benefit-cost ratio	3·22	1·34
(8)	Returns to research in dry farming		
	internal rate of return (per cent)	113	94
	benefit-cost ratio	22·54	9·36
(9)	Returns to wheat research	125	150
	internal rate of returns (per cent) benefit-cost ratio	31·68	12·5

Note: Price are deflated by GNP price index, 1967–69 = 100.

By assumption, investment in the projects stopped in 1973. In 1974 and on, yield will be maintained at the level predicted for 1974. The annual value of the contribution of research will, by assumption, be constant at I£. 17 million yearly. This is an underestimate of the contribution of research, for two reasons: (a) it can reasonably be expected that yields will increase with time due to learning and shifts to better varieties in the group of 'new' varieties; (b) yields of the Florence variety would have decreased, thus increasing the future contribution of the replacing varieties.

It was assumed that to maintain future yields at their 1974 level, research will be continued at the current level—an outlay of I£. 1 million annually.

In the calculations of Table 4, net annual future benefits of the research project is the money value of future yield differential *plus* the flow equivalent of past benefits (in this way, past returns are transferred to the future), *minus* cost of maintainance research. Prices are 1967–9 prices, thus recent inflationary trends and changes in terms of trade of agriculture are not reflected in these calculations.

As stated earlier, three alternatives were taken as investment in research: (a) research in wheat over the period 1954–73; (b) dry farming research; and (c) field crops research. Cost of research was estimated by Ariel Dinar [*1974*].

The returns were calculated in two ways:

(a) As an internal rate of return; this is the discount rate equalising the capitalised values of past and future costs and benefits of the project.

(b) As benefit cost ratio; namely, as the ratio of the present value of the benefits (past and present) to the capitalised value of the cost.

The last three lines of Table 4 show the alternative values of the returns. The calculated internal rate of return varies from 16 per cent for research in the field crops to 125 per cent for research in wheat. The corresponding benefit–cost ratios are 3·22 and 30.

REMARKS ON THE ROLE OF THE INTERNATIONAL RESEARCH CENTRES

We conclude this case study on the transfer of technology from an International Centre to a recipient country with a few remarks on the future role of these research institutions and the interrelation between international and domestic research.[8]

To some extent, research in the International Centres substitutes domestic, national research. Our study, however, revealed a case of strong complementarity. The creation of the new Mexican wheat varieties revolutionised the Israeli wheat research and it is doubtful whether these varieties would have been successfully adopted without the local effort. In this process CIMMYT (and the Rockefeller Programme before it) contributed the major wide-base advancements and the indigenous research systems selected and adopted the international techniques to local conditions.

In general, this division of labour between local and international research, if properly done, will be according to comparative advantages. The centres will concentrate on the more general innovations and domestic research on locally-specific. The experience of the Rockefeller Programme in Mexico is highly indicative in this respect. The Programme was very successful in wheat, while its maize project was, comparatively, a failure exactly because the latter crop is geographically sensitive while the new wheat types are not [*Meyren, 1968*].

It is useful to view research, particularly plant or animal breeding, as a search within a distribution of potential genetic combinations.[9] In terms of this framework, the major advantage of the International Centres lies in their size and wide outreach. By concentrating on a single crop (or a small group of crops), and having enough resources 'to cover the world' in their area of concentration, the international centres both increase the variance of the population they search and their potential to affect the outcome of their search through appropriate choice of parental breeding material (IRRI—the International Rice Research Institute in the Philippines—maintains a collection of 15,000 rice varieties to draw upon in search for desired characteristics).

The first Centres, CYMMIT and IRRI, have been very successful [*Dalrymple, 1974*] partly because of the gap between agricultural research in the moderate climate zones and research in the tropics and the subtropics [*Boyce and Evenson, 1975: Table 1.11*]. To a large extent this was done by substituting international research for domestic works. Varieties developed in these Centres were planted throughout the world after a relatively short test. Our finding of strong complementarity between the levels of research suggest that the Centres may pass an interesting life-cycle: the contribution of international research will enhance the productivity of domestic research, governments will invest more in manpower and equipment, this will, in turn, increase the contribution of the International Centres but, at the same time, it may lower their relative position *vis-à-vis* the indigenous research systems. Even if this scenario materialises the

Centres will maintain a crucial position as clearing houses for ideas and genetic material. It will be expensive and unwise for a single country to try and maintain variety collections of the size that the international centres will assemble. However, as sophistication and standardisation of research system will spread, as telecommunication improves, the importance of the physical concentration of international research work in one geographic locality can be expected to decline.

The Centres themselves reveal in their policies that they understand these developments. To augment the impact of their work, they maintain test plots in many countries and conduct courses for local specialists. Two recent developments at IRRI illustrate this trend beautifully.

In 1975 IRRI established the International Rice Testing Programme—a network of co-operating systems in the rice-growing countries in which varieties are developed and tested simultaneously in several localities with 'IRRI, as a coordinator, multiplies and distributes sets of seeds . . . data from all locations are sent to IRRI to be compiled, published and distributed' [*IRRI Reporter, 2/75*]. Scientists in domestic systems can request information and genetic material through IRRI.

In further recognition of this change of emphasis, IRRI announced a new policy naming rice varieties. In the words of Dr. Nyle C. Brady, IRRI Director General:

> Since the first variety of the International Rice Research Institute (IRRI), IR8, was released in 1966, IRRI's policy has been to officially release and name new rice varieties. This practice has served a purpose in calling these varieties to the attention of scientists and production specialists in rice-growing countries throughout the world. However, marked expansion in national rice improvement programmes and the development of international co-operation through the recently expanded International Rice Testing Programme appears to make this practice no longer necessary. Accordingly, IRRI will no longer officially release and name rice varieties. It will leave to the national organizations the responsibility for such releases.
>
> IRRI will continue to make breeding material available to all nations, largely through the International Rice Testing Programme. All rice improvement programmes will be encouraged to utilise IRRI material and to release IRRI selections as varieties, using names or designations of their own choice. [*IRRI Reporter 1/76*].

Another aspect of agricultural research should be brought up at this point. The first success of the international centres were concentrated in the more applied areas. There has simply existed a wide, hitherto untapped pool of applicable theoretical knowledge. As this pool is exploited, further advancements will be on the frontiers of knowledge and will require the co-operation and cross-fertilisation of agricultural research and 'purer' scientific work as plant physiology, theoretical genetics, biochemistry.[10] Though economies of scale evidently exist in any research work, they are in pure science of a different nature than in the more applied areas of agricultural research. This will also increase in the future the relative importance of national research.

Thus, the more successful the present efforts of the International Centres, the faster the decline of their relative importance (even as their absolute contribution to agricultural production may be rising). It should be emphasised at this point that this conclusion is based in the present study on the case of Israel, a country with a technologically advanced agriculture and a strong research base, but it is also supported by evidence from the developing areas. It should also be noted that only two of the Centres have already 'matured'—the others are just starting now. It will take many years and hard work for them to approach the levels of success of CIMMYT and IRRI. The lesson for the developing countries still is that the establishment of the International Centres does not free them from domestic investment in agricultural research, it enhances the economic justification of this kind of investment.

NOTES

1. Average precipitation in the wheat growing area ranges from 250 to 700 mm per annum.
2. Fertilisers consumption in the world has increased at a similar rate [*Evenson and Kislev, 1975: Chapter 2*].
3. Two additional varieties, Minka and Gabo (the outcome of early Israeli breeding efforts), were included in some of the estimates.
4. Several other specifications were also tried with essentially the same results. The double-log (Cobb–Douglas) specification which allows for complementarity of factors was preferred on *a priori* grounds.
5. Rain distribution is sometimes thought to be more important than its total quantity, but several attempts to incorporate distributional information in the regressions did not yield superior results.
6. Note, however, that for the country-sample-regression the time coefficient was barely significant at the 10 per cent level. Too much weight should therefore not be given to this explanation in the text.
7. As wheat yields rose, wheat area expanded, the area of barley and sorghum declined. Our procedure of calculating the benefits implicitly assumes that the values of production per hectare of these two crops were, at the beginning of the period, the same as that of wheat. This introduced an element of over-estimation into our calculations. By our judgment, this element is insignificant.
8. Eleven International Agricultural Research Centres and related institutions have been or are about to be established. Their work is co-ordinated through the Consultative Group on International Agricultural Research headed by the World Bank [*Boyce and Evenson, 1975: 53–61*].
9. For a formulation and elaboration, see Evenson and Kislev [*1976*].
10. See in this respect Evenson [*1968*] and Evenson and Kislev [*1975: Chapter 2*].

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