CASE STUDY

THE ROCKEFELLER FOUNDATION PROGRAM IN CORN AND WHEAT IN MEXICO

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Reprinted from *Subsistence Agriculture and Economic Development*,
edited by Dr. Clifton R. Wharton, Aldine Publishing Co., Chicago, 1969.

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Preface

The article reprinted here is part of the book *Subsistence Agriculture and Economic Development* edited by Dr. Clifton R. Wharton, Jr., and published by Aldine, in 1969. It is one of four case studies on the execution of agricultural development. Dr. Wharton introduces this study as follows:

"Intensive agricultural research to develop dramatic improved agricultural technology is frequently advocated as indispensable for a breakthrough from subsistence to commercial agriculture. The prototype for most current approaches is the work of the Rockefeller Foundation in Mexico, which began in 1943 as the Office of Special Studies and is now being continued as the International Center for Maize and Wheat Improvement.

"In his case study of the Mexican program, Dr. Delbert T. Myren examines the 20-year experience of the program in an attempt to unravel the puzzle of its greater success in the case with wheat than with corn, despite almost identical professional resources and research approaches which led to equally significant technological breakthroughs. Dr. Myren advances four main explanations:

"1. Between the two crops there were important location differences, with attendant differences in the quality of the land, especially irrigation. More wheat was irrigated than corn; and corn was predominantly dependent upon rainfall.

"2. Corn producers are different from wheat producers because the former are heavily subsistence while the latter are commercial and have a higher level of literacy.

"3. Probably the most important explanations for the differential success of wheat over corn lie in certain technical differences between the two crops:

(a) In wheat the new varieties gave protection against heavy disease losses, whereas in corn there was no single serious disease problem.

(b) The seeds for the new hybrid corns had to be purchased each new planting season, whereas the open pollinated wheat could, if necessary, be duplicated by the farmer or by his neighbors.

(c) In the case of wheat, the genotype maintains itself for an indefinite period, whereas the hybrid corns require a highly competent and efficient seed-multiplication agency to maintain their hybrid vigor.

(d) The new hybrid corn had inherently lesser ecologic adaptability than the improved wheat varieties, which meant that corn required greater local-specific research and development to accommodate for its greater temperature sensitivity.

"4. Finally, there is eight times as much corn acreage as wheat, and there are forty times more corn farmers than wheat farmers. These important differences in numbers and size between the two crops seriously affect the ease with which the new technology can be spread utilizing accepted methods of extension education.

"Dr. Myren's case study offers an excellent analysis of the important considerations that must enter into the strategies involved in an intensive concentration of resources to achieve major technological breakthroughs."

CASE STUDY

The Rockefeller Foundation Program in Corn and Wheat in Mexico

DELBERT T. MYREN[1]

THE COOPERATIVE PROGRAM[2] between the Mexican Ministry of Agriculture and the Rockefeller Foundation has been hailed as an exemplary case of collaborative effort in agricultural research [Mosher, 1957, pp. 100–126; Schultz, 1964; pp. 148–149; Stakman et al., 1967]. The two crops that received major attention from the very beginning were corn and wheat—two of Mexico's basic food crops. A similar investment has been made during the past 20 years in each crop—in salaries of research workers, in equipment, in scholarships for advanced training of junior scientists, in extension effort. Yet if the results of work with these crops are measured in terms of the change in yield per unit area on a national scale, one finds a sharp contrast between the two. Average corn yields in 1940 were 626 kilograms per hectare; in 1960 they were 839 kg/ha.[3] Average wheat yields in 1940 were 763 kg/ha; in 1960 they were 1,341 kg/ha. Thus, over the 20-year period corn yields increased 34 per cent, while wheat yields went up 76 per cent—more than twice as fast. The difference

1. I am grateful to Dr. Edwin J. Wellhausen and Dr. Norman E. Borlaug, the scientists who initiated and have guided for two decades the corn and wheat research referred to, as well as to Dr. Elmer Johnson, corn geneticist of the International Center for Corn and Wheat Improvement, for their critical reading and comments on the manuscript. The interpretation of the available evidence is the author's own.

2. Established in 1943 and operated through an Office of Special Studies from 1945 through 1960. Cooperation continues at present through the International Maize and Wheat Improvement Center.

3. The metric system is used throughout this article. For a quick conversion of yield figures, the shelled corn yields in kg/ha can be multiplied by 0.01593 to obtain bushels (56 lbs.) per acre. Use 0.01487 for converting wheat kilos to bushel (60 lbs.) yields. For example, one metric ton (1,000 kgs) per hectare of corn is equivalent to 15.93 bushels per acre.

accentuated from 1960 to 1963, with wheat showing a yield per unit area gain of 54 per cent while corn yields remained about constant.[4] Preliminary figures for 1967 show corn yields well above one ton (1204 kg/ha) —a 44 per cent gain over 1960. Wheat, however, gained substantially more, putting the average 1967 yields for the entire country at 2,800 kg/ha, or 109 per cent above those of 1960 and 267 per cent above those of 1940.

Total production of both crops has also advanced because of an expansion in area. However, the main concern of this paper is with the introduction of improved technology and therefore yield per unit area will be the most relevant measure.

We have in wheat and corn two parts of a single program of directed change which show quite different results. It should be productive to attempt to isolate the components of the why?

Developing The Package of New Technology

EARLY HISTORY OF CORN AND WHEAT

The plant scientists who initiated the cooperative corn and wheat improvement programs in 1943 were dealing with crops that had been grown in Mexico for a long time. Wheat was brought by the Spaniards soon after the conquest and found to be well adapted to the soil and climate of Mexico. Corn is indigenous to Mexico, and evidence has been found of its cultivation prior to 5000 B.C. Natural selection occurred over the years in both crops, resulting in better adaptation of the existing varieties. In all likelihood ample crossing also took place, especially in the case of corn, between local varieties and new ones brought in by traders and other travelers.

From such selection the lines would have been preserved that yielded seed to reproduce themselves and, insofar as man intervened, those that produced the greatest amount of seed for human food. In this way the most productive varieties were developed for the conditions under which corn and wheat were grown. The kind of selection that took place in corn is evident in present-day varieties still grown in various parts of Mexico. Obviously this selection was not directed toward obtaining the highest possible yield under optimum conditions, but rather toward the selection of lines that would yield something even under the worst conditions. The severity of drought and other conditions for which natural selection took place varied greatly from one area to another and consequently led to enormous variety in the native germ plasm found in Mexico.

Assuredly yields must have moved up as the early cultivators of corn, and later those who introduced wheat, learned better cultivation practices through experience. However, as we move into the second quarter of the present century and are able to trace what is happening through statistics collected annually by a government agency, we find both corn and wheat yields nearly static for the two decades from 1925 to 1945. The lowest and highest annual corn yield for 1925–1929 was 513 and 698 kg/ha, and the corresponding figures for wheat were 646 and 729 kg/ha. These moved along together with a slow rate of increase, perhaps owing principally to new fertile land being brought into production, until the mid-1950's, when wheat yields began to move sharply ahead of corn, as can be seen in Table 13.16.

Table 13.16. Highest and Lowest Annual Average Yields of Corn and Wheat in Mexico by 5-Year Periods, 1925–1964

	CORN		WHEAT	
	Lowest	*Highest*	*Lowest*	*Highest*
1925–29	513	698	646	729
1930–34	448	633	703	869
1935–39	545	605	708	864
1940–44	491	690	710	815
1945–49	634	761	740	941
1950–54	721	854	863	1,098
1955–59	803	880	1,063	1,592
1960–64	946	1,133	1,471	2,056
1965–67	1,090	1,204	2,400	2,800

SOURCE: Direccion General de Economia Agricola; the 1965–1967 data are still considered preliminary.

4. The first figures are based on census data; the other are data of the Direccion General de Economia Agricola, Mexico. The reporting year for the 1960 census was May 1, 1959, to April 30, 1960, thereby including the principal irrigated wheat harvest of May and June 1959 but not that of 1960. The figures of Economia Agricola cover the calendar year. Therefore, in speaking of yield gains for the most recent four years, the Economia Agricola figures are also used for the base. Wheat yields in kg/ha or 1960–1963 were respectively: 1,417; 1,676; 1,946; 2,187. Corn yields in kg/ha for 1960–1963 were respectively: 975, 993, 995, 946.

It was during this period that the plant scientists who formed the cooperative corn-and-wheat-improvement programs entered the picture. Starting with a one-man Rockefeller Foundation task force in 1943, by the mid-1950's the group had grown to 18 Foundation staff and about 100 fulltime Mexican associates, many of whom had received advanced training abroad under Foundation scholarships. The results of the program are amply documented in annual reports, books, and published papers [Harrar, 1963; Stakman et al., 1967], so I shall not go into a general description of the program. What interests us here is how new knowledge was brought to bear on problems of wheat and corn production and whether there were any important differences between the approaches used on the two crops.

THE RESEARCH APPROACHES ON CORN AND WHEAT

There was actually considerable similarity in the broad outline of attack.

1. A team of outside scientists—made up of a plant pathologist, a geneticist, and a soil scientist—traveled through more than 5000 miles of Mexico's agricultural areas and recommended the approach and general lines of research that appeared to offer most promise.

2. This scientific observation tour led to the selection of certain types of individuals for the research posts. The most serious limitation to wheat production appeared to be stem rust, and recent experience in the United States had suggested that important progress could be made through incorporating genetic resistance. A plant pathologist with a strong genetic background was chosen to lead the wheat-improvement work. For the corn program, where no single disease limitation was evident, a geneticist well versed in the production of the new hybrids that were revolutionizing yield expectations in the corn belt was obtained for the research post. A soil scientist and an entomologist were added to study what appeared to be other serious yield limitations.

3. These specialists had several characteristics in common. They were relatively young. They had top scientific preparation in a field that was judged to have real potential for solving an applied problem. They had previous practical experience, and they were looking for a challenge. Within their persons they were carriers of the best knowhow that had been developed in other areas. Equally important, they knew the main sources from which additional information could be quickly obtained.

4. Young graduates of local agricultural colleges were given specialized in-service training with both the wheat and corn research programs, and the most promising were sent abroad for advanced study, first at the Master's and then at the Ph.D. level. These young local scientists provided additional information links with specialized research programs under way in the United States. As they completed their specialized training, they also perfected their knowledge of English and specialized vocabulary, making the major scientific journals of the world readily accessible to them.

5. Simultaneously a well-organized technical library was established, to assist scientists in keeping contact with latest research methods and theory from other parts of the world.

6. A policy of prompt release of research results was established from the beginning and applied equally to corn and wheat.

There were also differences. As the work progressed and new varieties were ready for release, corn and wheat took slightly different tacks. In the case of the corn hybrids, a governmental organization, the National Corn Commission, was set up in 1946 under the Ministry of Agriculture to handle seed multiplication and distribution. In the case of wheat, where the genotype perpetuates itself unchanged and the only possible problem is mechanical mixing of the seed, multiplication and distribution has been handled mostly by private farmers. The ministry has limited its intervention to the first increase and to a voluntary seed certification program.

The nature of the product was also different. As corn is an open pollinated plant, new seed of the hybrids had to be purchased each year in order to get full benefit of the hybrid vigor. The self-pollination of wheat meant that a farmer could buy a small amount of the new seed, multiply it himself, and then grow it as many years as he wished. But in both cases an effort was made to assure that all interested farmers should receive seed. In relation to this, Dr. Sterling Wortman comments as follows:

I think that there was one additional difference between the wheat and corn programs in Mexico, at least as I recall the situation when I was in charge of corn from 1951–1954. As I look back I realize that in the corn program we primarily had a plant breeding effort under way, not a comprehensive production program of which plant breeding was a necessary part. We were concerned very much with the problem of developing the many varieties of hybrids needed for the great number of ecological situations in Mexico and we carried this program to the point of producing foundation seed for the National Corn Commission. We did not, unfortunately, measure our own progress by what happened to the national average yields of corn in Mexico. Rather we worried about getting enough foundation seed to the Corn Commission to allow it to plant the projected acreage of single crosses for the production of doubles. The wheat program on the other hand was concerned not only with development of rust resistant, high yielding varieties but with seed production, the use of higher amounts of fertilizer, and adoption by farmers. [Personal communication]

In summary, the way of bringing knowledge to bear was on the whole similar for both crops. Has equal research progress been made?

RESEARCH RESULTS: EXPERIMENTAL AND FARMERS FIELDS

The highest possible yields are a good reflection of the level of technology currently available. In both corn and wheat, not only the research workers, but also farmers have made efforts at different times to obtain maximum yields. Other progressive farmers are using modern technology to obtain a lower level of yields that they consider optimum. If the distance between the two is great, it may be possible to change procedures or costs to raise the optimum level of production without a change in the basic technological components.

Interestingly, the highest-recorded corn yields are well above those of wheat, both on individual experimental plots and where farmers have tried for maximum yields without considering cost. In fact, experience with yield contests has shown that a farmer may give the same care on a larger area that the scientist gives on small plots and obtain similar results. In the case of corn this means special attention to: (1) selecting a fertile piece of land that is level, of uniform quality, and has good drainage; (2) overplant and then thin out by hand in order to obtain an optimum number of plants, uniformly distributed; (3) irrigate with sufficient frequency, so that the plants have an optimum water supply available at all times; (4) use proper fertilizer in excess of usual needs and apply it at intervals, to assure an optimum supply available to the plant at all times; (5) cultivate by hand as needed, to avoid any detriment from weeds.

Providing this kind of care, in 1957 one farmer in the valley of Mexico obtained a yield of 15 ton/ha of dry shelled corn (15.5 per cent moisture content) on 1.7 hectares with the hybrid H-125 [Itie, 1957]. Earlier, in 1950 and 1951, two farmers in the Valley of Mexico had obtained yields of 12.96 tons and 12.20 tons per hectare of dry shelled corn (15.5 per cent moisture) on 1 hectare and 20 hectare lots, respectively, with the hybrid H-1. In 1954 another farmer in the Valley of Mexico, an *ejidatario*, obtained 12 ton/ha on a 4-hectare plot of H-1 (Diaz del Pino, 1957].

An optimum population of corn is crucial for obtaining high yields. In fact, as fertilization is increased, plant population must also be increased in order to get maximum yields [DAG, 1964, p. 95]. For wheat, on the other hand, although much of the same special care is essential, the heavy labor investment in overplanting and hand thinning is not needed because of the plant's tillering ability. For example, in one wheat experiment with 25 varieties, including all of the commercial ones and using recommended fertilization rates, there was no statistically significant difference in yield between seeding rates of 60, 80, 100, and 120 kilos per hectare [Rockefeller, 1958, p. 120].

A top wheat yield in 1957 was about 6.5 tons. The best farmers were getting at the most 6 tons/ha in commercial production. Today the best farmers are getting 8 ton/ha on acreages of 50 hectares and over.[5] The wheat

5. This yield information was provided by Dr. Ignacio Narvaez, wheat specialist of Mexico's National Institute for Agricultural Research; that on corn, which follows, is from Dr. Elmer Johnson, Rockefeller Foundation corn geneticist.

breeders credit the higher level of the top yields to a continuous improvement of yield potential of the new varieties and to the fact that farmers have simultaneously learned to manage more precisely the key factors of production, such as land leveling—which permits more accurate water management—density of planting, timing, and amount of fertilizer application and insect control. However, they estimate that the varieties grown in 1950 would not yield over 3.5 ton/ha today under the very best care. Thus, under optimum conditions the increment attributable to variety changes alone is calculated at 4.5 ton/ha. In addition, the new varieties are an insurance policy against a complete loss from stem rust, such as sometimes occurred with the old varieties.

In corn, the increment in yield because of varietal changes alone is estimated in more modest terms. Where original varieties have been compared in recent years with the best hybrids for a region, the gain averaged about 35 per cent. Interestingly, the evidence indicates that the best obtainable yields with the varieties that existed 20 years ago were substantially higher for corn than for wheat. Even with present varieties and technology for the two crops, it appears that the top level of corn yields is well above that for wheat and probably has been at all times during the past two decades. In other words, it is not the yield ceiling that has kept down average yields in the case of corn relative to wheat.

Possible Explanations for Yield Differences Between Corn and Wheat

Based upon experience to date, there are four areas that may offer possible explanations for the differences in yields between corn and wheat.

Locational Differences and Quality of Land

Both corn and wheat are grown on substantial land areas, but the acreage is greater in the case of corn. In 1960 the harvested area of wheat was 846,162 hectares, while that of corn was 6,802,491, or eight times as much.

Much more relevant is the quality of land involved, and here we see an important difference that has resulted from shifts in the predominant locations where the crop is grown. There has been a substantial geographical shift in wheat production. In 1940 the main wheat-producing area, accounting for 43 per cent of the harvest, was the central part of Mexico, especially the Bajio region. The northwest produced 17 per cent. By 1950 the northwest had 30 per cent of the wheat acreage and 38 per cent of the harvest. In 1960 this had grown to 38.5 per cent of the acreage and 46.5 per cent of the harvest. By 1964 the northwest accounted for 54.5 per cent of the wheat area and 71.5 per cent of the harvest.

Because of the expansion in the total area planted to wheat, up to 1960 the percentage reduction of area in the other production regions took place without reducing total area planted. In fact, in Guanajuato of the center and in Zacatecas, Nuevo Leon, Chihuahua and Coahuila in the north there were substantial increases in area planted. By 1964, however, the area planted had dropped off again sharply in the north, especially in the states of Coahuila, Durango, and Zacatecas, as well as in the states of Guanajuato and Puebla in the center region.

A geographical shift in production area might account for an increase in yields if the shift was to better land or from poor rainfall to good rainfall or irrigated areas. There was no indication of such change in the data of the past three censuses, which show 73.4 per cent of the wheat land under irrigation in 1940, 72.3 per cent in 1950, and 68.3 per cent in 1960. However, yearly data since then show a growing predominance of irrigated production. There is a problem in making comparisons here because of a substantial discrepancy between the census data and those of the Direccion General de Economia Agricola. There is reason to believe that the data of the DGEA are more accurate in this case. Theirs show 82.4 per cent of the harvested wheat area under irrigation in 1959, 84.3 per cent in 1960, 87.8 per cent in 1961, 87.4 per cent in 1962, and 89.0 per cent in 1963. According to these same figures, 93.7 per cent of the total wheat harvest was produced under irrigation in 1962 and 95.2 per cent in 1963.

The geographical shift in corn production has been relatively minor, and because of the vagaries of natural rainfall cultivation, a

Table 13.17 Geographical Distribution of Corn Production Percentage of Area and of Production, by Region for 1940, 1950, 1960, 1964.

Region	1940 Area %	1940 Prod. %	1950 Area %	1950 Prod. %	1960 Area %	1960 Prod. %	1964 Area %	1964 Prod. %
North	23.91	19.77	25.24	21.79	23.70	20.71	19.31	15.57
Gulf of Mexico	9.07	14.24	9.03	11.51	11.22	12.63	15.30	18.32
Pacific North	4.88	6.78	4.84	6.39	5.17	7.74	3.50	4.23
Pacific South	12.80	13.56	16.92	18.10	18.88	18.72	13.51	12.44
Center-High Valleys	20.56	21.13	18.03	17.40	17.19	17.80	16.93	13.13
Center-Bajio	28.78	24.52	25.94	24.81	23.84	22.40	31.45	36.31
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The 1940, 1950, 1960 data are from the national census. Those for 1964 are preliminary estimates of the Direccion General de Economia Agricola.

larger sampling of years than available at present should be analyzed. There does, however, appear to be a definite increase in both percentage of area and percentage of production in the gulf states and in the Bajio, while the states of the central high valleys have decreased on both counts. There may also have been some decrease in the north (see Table 13.17).

As in wheat, part of the shift has been from low-yield areas to new lands, in this case the gulf states. In addition, the amount of land planted to corn appears to be increasing again in the Bajio, where yields had stagnated at a low level but in the past few years have increased notably (see Table 13.18). In spite of this, the geographical shift in corn production has been of minor proportions compared to that for wheat.

The census figures on crop area lost provide a further indication of the better quality of land used in wheat production. The 1940, 1950, and 1960 data show that the planted corn area that was not harvested varied from 16.1 to 18.0 per cent, while that for wheat varied from 12.0 to 13.1 per cent. The majority of corn crop failures were due to drought, varying from 9.1 to 14.2 per cent. In wheat, drought was also the leading cause (up to 6.6 per cent) but was followed closely by frost and, in descending order, insects and diseases, flooding, hail, and others.

The tabulation of corn acreage according to natural rainfall or irrigated production is available only from 1959 through 1962. However, during that four-year period there was no obvious shift from one to the other, the percentage of irrigated area being respectively 9.53, 9.17, 9.23, and 9.91, accounting for 17.38, 9.98, 14.74, and 14.95 per cent of the total production. The extent of advantage that could be gained from this kind of shift is evident in Table 13.19.

Clearly, natural-rainfall yields of wheat have not moved ahead of corn. In fact, the yields of corn grown on residual moisture are ahead of wheat. Only in the irrigated area does the scale tip heavily in favor of wheat. This, added to the fact that most of the wheat acreage is now on irrigated land, explains

Table 13.18. Corn Yields by Regions (in Kilograms per Hectare), 1940–1964

Region	1940	1950	1960	1959	1960	1961	1962	1963	1964	1965	1966	1967
North	518	683	733	655	745	734	750	621	914	794	755	631
Gulf of Mexico	983	1,008	944	1,097	1,161	1,059	1,052	1,443	1,357	1,471	1,650	1,650
Pacific North	870	1,044	1,257	1,386	1,282	1,523	1,522	1,324	1,372	1,799	1,217	1,634
Pacific South	664	846	832	939	972	960	964	1,018	1,043	989	917	898
Center-High Valleys	644	763	869	781	764	751	763	629	879	979	934	949
Center-Bajio	534	757	788	884	1,067	1,144	1,140	969	1,308	1,223	1,377	1,664
Mexico as a whole	626	836	839	880	975	993	995	946	1,133	1,124	1,090	1,204

The first three columns are Agricultural Census data, and the others are from the Direccion General de Economia Agricola of the Mexican Ministry of Agriculture.

Table 13.19. Average Corn and Wheat Yields (in Kilograms per Hectare) on Three Types of Plantings Over a Four-Year Period, 1959–1962

	CORN		WHEAT	
	Lowest	*Highest*	*Lowest*	*Highest*
Natural rainfall	772	962	860	972
Residual moisture	1,043	1,463	881	1,002
Irrigated	1,062	1,587	1,447	2,086

SOURCE: Direccion General de Economia Agricola.

much of the difference in average yields per hectare. It does not explain, however, why more of the yield potential of corn is not being realized in its irrigated areas.

THE PRODUCERS OF CORN AND WHEAT: SUBSISTENCE VERSUS COMMERCIAL ORIENTATION

Another possible explanation for the failure to exploit the yield potential of corn in irrigated areas might be found by taking a closer look at the people who decide which crops to grow, which seeds to plant, and on what land to plant them—the individual farm operators. Their decisions may be affected by a number of factors—by past experience, by access to new information, by access to markets, by price expectations (which may in turn be stabilized by government), by availability of resources for purchasing new inputs, and by many other factors. But in the final analysis it is the sum of their individual decisions on the adoption of new practices that determines the level of technology used on a national scale in corn and wheat cultivation.

Are there any differences in the kind of decision-makers who grow corn and wheat?

In spite of the fact that numerous farmers grow both crops, the average wheat producer and the average corn producer are indeed quite different. The wheat farmer tends to be the operator of a commercial farming enterprise; he grows his crop under irrigation and sells it, either directly or indirectly, to the millers for processing. Considerable corn is also produced for sale, but the vast majority of farmers who grow corn do so first of all to provide food for the family (often interplanted with beans, in an attempt to assure some production of the two most basic subsistence crops) and secondly to produce a marketable surplus.

Although we have no accurate figures on the number of farmers who grow wheat and corn, one indication is provided by the 1960 census in a classification of farms by predominant crop. Corn predominates on 748,378, or 54.8 per cent, of the farm units,[6] while wheat predominates on only 28,388, or 2.1 per cent. It is probable that corn is grown on at least two-thirds of the farms by some two million farm families, while wheat is grown by less than 50,000. If so, there are 40 times more corn farmers than wheat farmers, and consequently 40 times as many decision-makers to be reached with information about new production practices. If this is true, it also indicates something about problems of mechanization of the two crops, as the average wheat land per farmer would be about 17 hectares, while the average for corn would be about 3 hectares. These, of course, are rough estimates at best.

The census data, as presented, offer only one clue as to the type of farmers who grow wheat and corn. Acreage data for the two crops is given under a three-way tenancy classification of *larger than five hectares*, *five hectares or less*, and *ejido*. The percentage of wheat land is least on the small private farms and has tended to drop off from 1940 through 1960. These same farms have more than 80 per cent of their harvested area in corn, and this has tended to move up slightly during the same period. In contrast, the percentage of area in corn among the larger farms dropped off from 71.2 in 1940 to 64.1 in 1950 and 61.4 in 1960. In the *ejido* sector there appears to be a slight percentage drop in both crops from 1940 to 1950 and then a slight rise again in 1960 as shown in Table 13.20.

The corn/subsistence and wheat/commercial distinction, though not wholly appropriate in all cases, does highlight the importance of the shift in emphasis from security to profitability as a farmer moves from subsistence toward greater commercial production or, conversely, in areas of growing rural

6. In this case the census considers each *ejido* a farm unit, even though, as is now usually the case, the land area has been officially parceled and most farming decisions are made by the individual *ejidatarios*. In 1960 there were 18,699 *ejidos*, with 1,597,691 *ejidatarios*. In addition there are 1,346,442 private operators.

Table 13.20. Percentage of Total Farming Area in Corn and Wheat by Farm Class for 1940, 1950, 1960

	1940		1950		1960	
	% in corn	*% in wheat*	*% in corn*	*% in wheat*	*% in corn*	*% in wheat*
More than 5 ha.	71.2	7.8	64.1	7.3	61.5	10.7
5 ha. or less	83.6	4.2	86.2	3.5	86.2	3.2
Ejido	67.7	9.6	65.2	6.0	66.3	6.5
Average	70.9	8.3	66.8	6.3	65.6	8.2

SOURCE: National Census data.

population and static technology, a shift to corn in order to have the security of an adequate harvest of the basic food crop. It is evident that whoever grows a crop—an *ejidatario*, a small or a large private operator—does so for economic reasons. As soon as he is in a position to produce something beyond what his family consumes, he becomes concerned with profitability [Myren, 1964]. In this case the relative profitability of the two crops is especially pertinent because corn can be grown successfully wherever wheat is currently produced, although in most places not during the same growing period.

The main problem in getting a fair comparison of relative profitability of corn and wheat under field conditions is the great variation of managerial ability among the farmers who grow the two crops. For this kind of comparison we have to go to the Bajio region, where many farmers grow both crops under irrigation. Data for 1960 from 16 of these farmers show the following average results:[7]

	Corn	*Wheat*
Total area (ha)	464.00	774.00
Yield (kg/ha)	2,477.74	2,576.87
Value of production (pesos/ha)	2,146.19	2,413.31
Cost (pesos/ha)	2,066.51	2,071.67
Net return (pesos/ha)	79.68	341.64

Twelve had higher returns with wheat and four with corn. On the average, and in spite of the demonstrated higher yield potential of corn, these farmers achieved greater average profits from wheat than from corn. Costs were nearly identical, and the difference in profit was due principally to yields and the higher support price for wheat.

7. Based on data provided by the Departamento de Economia Agricola, Instituto Nacional de Investigaciones Agricolas, Mexico.

Since then, however, two important changes have taken place. On the one hand the corn guarantee price has been raised from 800 to 940 pesos per ton, while wheat has remained at 913 in the Bajio, drastically changing the relative profitability of the two. (During the past four years the guarantee price for wheat in the northwest has been adjusted downward to permit sales on the world market at a relatively small loss for the price-support agency.)

Another interesting and closely related factor has been the influence of commercialism when linked with a technology that required continual change. In the case of wheat, initial success coupled with an ever-changing technology contributed to the development of farmer entrepreneurs who began to look to agricultural science as a handmaiden in their mastery of nature.

Undoubtedly the precondition for the takeoff in wheat yields was the water-resources policy of the Mexican government, which was responsible for constructing the dams and canals for irrigating the desert valleys of the northwest coast. The initial breakthrough in wheat improvement was made by the scientists who found that they could produce varieties resistant to steam rust, thereby providing insurance against the heavy losses that sometimes occurred with existing susceptible varieties. This stimulated the farmers to make heavier investments in fertilizer and in equipment for better land preparation, as well as to give greater care to the crop, especially in applying irrigation. It also stimulated public and commercial investment in farm credit, machinery, and fertilizer distribution. With readily available inputs and assurance of higher yields, the irrigated area planted to wheat expanded rapidly.

It turned out, however, that the production of improved varieties was to be a continuing battle. The races of stem rust have shown remarkable talent at hybridization and mutation, producing new races that again and again have threatened wheat harvests, especially in the northwest, where production was expanded most rapidly. Fortunately the research program has anticipated this eventuality and has been able to quickly offer new varieties.

As farmers continued to increase fertilization rates, another problem appeared—serious yield limitations because of lodging. To contend with this, dwarf varieties incorporating the Japanese Norin strain were developed.

In the process of fighting stem rust and lodging, farmers have changed varieties at least a half a dozen times. In one case a single new variety came to dominate more than 90 per cent of the total area planted to wheat within three years after its introduction. Other varietal changes have been as rapid but have been distributed among several varieties with similar yield potential. Over the years farmers have profited by, and then discarded, the Kentanas, the Chapingos, the Gabos, the Yaquis, the Tolucas, the Lermas, the Lerma Rojos, and the Nainaris. More recently there has been a rapid shift to the dwarfs and semidwarfs—first the Pitics, Penjamos, Mayos, Sonoras, Nadadores, and Lerma Rojo 64, and now the 66's Tobaris, Jaral, INIA, Noroeste, Siete Cerros, Norteño, CIANO, Azteca, and Bajio—which today account for most of Mexico's wheat acreage.

Through the necessity of rapid change (where a new race of rust would cause disastrous results) farmers have learned much about wheat genetics. More important, they have developed an acute awareness of the possibilities of agricultural science for producing useful results and have come to view change as an expected and normal thing in their operations. In much the same way that North American farmers compare new models of automobiles, those of northwestern Mexico talk about the relative merits of the new wheat varieties. The experiment station has replaced tradition as the source of guidelines for agriculture. Now technology has helped to develop a "new breed" of farmer in the case of wheat. Corn was not so fortunate.

THE TECHNICAL DIFFERENCES BETWEEN CORN AND WHEAT

Perhaps the most important explanations for the differential success of corn and wheat lie in the technical differences between the two crops.

First is the fact, already mentioned, that in the case of wheat there was a serious yield limiting factor, in the form of stem rust, that could be effectively removed by plant breeding, thereby offering a dramatic yield increase at practically no cost to the farmer through the use of new seed. A single yield-limiting factor of this type was not present in corn.

Second is the lesser geographic and ecologic adaptabilities of hybrid corn, versus the improved wheat varieties. While the same varieties of wheat have given excellent results throughout the country, and in fact also in Pakistan, India, Egypt, and other countries [Borlaug et al., 1964; CIMMYT, 1967], the corn hybrids have had a more limited area of adaptation. Part of this is related to temperature. In Mexico wheat is grown in the high valleys in the summertime and in the other principal producing regions—El Bajio, La Laguna and the northwest coastal plain—in the winter, so that the temperature is somewhat similar in all cases. However, breeding methods have also influenced the development of varieties with very wide adaptation. Mexican wheat varieties have been among the highest yielding at locations from 0 degrees to 50 degrees latitude, over a wide range of longitudes, and under both irrigated and natural rainfall conditions. This is due in part to their insensitivity to changes in day length and date of planting and is in sharp contrast to the Canadian and northern United States spring-wheat varieties, which are all very sensitive to changes in day length [Borlaug, 1965].

The Mexican wheat varieties also differ from the corn hybrids in this sense. Although the best corn hybrid developed for natural rainfall plantings at sea level on the Gulf Coast is also the best one available for irrigated production at sea level on the northwest coast 3,000 kilometers away, this breadth of adaptation is not common. In order to obtain hybrids that yield better than local native varieties, it has generally been necessary te develop them for specific climatic conditions.

In most of Mexico corn is produced under natural rainfall and is grown during the June-to-October rainy season. The temperature during this period is much lower on the mountain slopes and in the high valleys than it is in the coastal areas. As the corn hybrids are very sensitive to temperature, this means that many different varieties or hybrids are needed in order to have one with optimum production potential for each situation. At the cool temperatures of high altitudes the best tropical variety develops extreme vegetative growth and takes nearly 12 months to mature, extending well beyond the frost-free period and the normal rainy season. As a result, there are still many areas of Mexico for which improved varieties or hybrids have not been developed. The present situation on hybrid corn use is reflected in the national census data (Table 13.21).

Table 13.21. Selected Measures on Use of Improved Corn Varieties on a National Scale, 1940, 1950, 1960

	1940	*1950*	*1960*
Average yield (kg/ha)			
Common variety alone	664	812	841
Common varieties interplanted with beans	486	666	636
Improved or Hybrid	[a]	1,621	1,471
Over-all average	626	791	839
Proportion of area in improved or hybrid corn	[a]	0.64%[b]	4.54%
Proportion of harvest from improved or hybrid corn	[a]	1.34%[b]	7.96%

[a] Not available for planting in 1940.
[b] Based on only the *ejido* and larger than 5-ha farms. The subdivision by kind of corn planted was not included for farms of 5 ha and under in the 1950 Census.

On the irrigated corn land a much higher percentage is planted to improved varieties and hybrids, as shown in Table 13.22. Less than 8 per cent of the land planted to native varieties is irrigated, in contrast to 32 per cent for improved corn. The corn hybrids have made an impact under good rainfall as well as irrigated conditions, but they have received by far the greatest acceptance for planting under irrigation.

13.22. Irrigated Land as Percentage of Total for Three Types of Corn Plantings

Common varieties alone	8.43
Common varieties interplanted with beans	6.15
Improved or hybrid	31.83
Average, all corn	9.14

SOURCE: 1960 Census Data.

Incidentally, the census comparison of the average yield of the improved varieties or hybrids with that of the native varieties may give a misleading impression of their relative merits. Hybrids show a distinct advantage, but not of the magnitude suggested by the census data, which does not show the higher percentage of irrigated land among hybrid plantings. This is pointed out, perhaps a bit too strikingly, in the data (Table 13.23) from a marginal rainfall area in the Bajio region, collected from farm operators in four municipios near Celaya, Guanajuato, and covering the period from November 1, 1959, to October 31, 1960.

We can move another step closer to seeing the actual benefits from improved corns under field conditions by comparing fertilized-irrigated hybrid with fertilized-irrigated native corn. Although we are dealing with small numbers here, Table 13.24 is at least suggestive of what happens.

Using these same figures as a basis for calculation, it appears that the cash return, after subtracting the cost of fertilizer, is nearly twice as great for fertilizer applied to hybrid as to the native varieties. On the average, the 9 native plantings received more fertilizer per unit area than the 15 hybrid plantings, but the hybrids yielded 450 kg/ha more, suggesting that where an adapted hybrid is available, it offers important yield potential.

So in corn growing we begin to see three basic systems of production, two of which overlap to some extent. At the one extreme we have typical subsistence farming, with native varieties interplanted with beans. At the other extreme we have the hybrids, seldom interplanted, frequently grown under irrigation, and usually fertilized. In between is the large number of farmers who still grow native varieties without interplanting and in many cases attain considerable success on irrigated land through adequate fertilization. A few others may plant hybrids for certain purposes and native varieties for others.

In the main producing areas, the recommended corn varieties have changed three or four times during the past two decades, and a

Table 13.23. Comparative Data on Corn Production Under Natural Rainfall and Irrigation for Selected Farmers in Bajio Region[a]

	NATURAL RAINFALL				IRRIGATED			
	No. of cases	*Area harvested (ha)*	*Production (kg)*	*Yield (kg/ha)*	*No. of cases*	*Area harvested (ha)*	*Production (kg)*	*Yield (kg/ha)*
Native corn interplanted	47	489.0	135,795	278	1	3.0	1,000	333
Native corn alone	24	496.5	180,072	363	16	480.5	1,144,700	2,382
Improved corn or hybrid[a]	7	235.5	98,750	419	18	385.0	1,158,970	3,010
	78	1,221.0	414,617	340	35	868.5	2,304,670	2,654
Improved corn or hybrid as % of total		19.29	23.82			44.33	50.29	

[a] This covers all plantings that farmers indicated as hybrid, including those from seed saved from previous hybrid plantings. In this area of low precipitation, only 8.9% of the natural rainfall plantings were entirely or partly hybrid, in contrast to 51.4% for the irrigated plantings.

number of progressive farmers have promptly followed the recommendations. Other farmers have benefited indirectly from new germ plasm introduced to an area through hybrid plantings and distributed by natural crossing with native varieties. The majority, however, have still to plant their first hybrid.

A third major technical factor favoring the rapid adoption of the new wheats has been the ready availability of good seed. When necessary, phenomenal increases have been obtained from small initial quantities of seed. On a trial basis Dr. Norman E. Borlaug, wheat scientist of the Rockefeller Foundation, has shown that it is possible to start with as little as 200 grams of seed and increase it to 150 tons within one year by using adequate fertilization, watering, spacing, and care. The 200 grams were seeded on October 5 and yielded 19 kilos in late February. Six kilos of this were set aside and the remaining 13 seeded at a rate of 8 kg/ha in the first days of March. A total of 3.8 tons were harvested on June 15 and immediately transported from the northwest to the Bajio, where 3.5 tons were seeded on June 18. This was seeded at a rate of 100 kg/ha on 35 hectares, and 150 tons were harvested in October, in good time for winter plantings. In going from 200 grams to 150 tons, the seed supply is increased 740,000 times in one year. Two additional increases would provide more than all of the 80,000 tons of seed wheat used annually in Mexico.

The improved wheat varieties also have the advantage that the genotype maintains itself for an indefinite period. This means that if wheat seed is made available to 20 farmers, from the following harvest they can each distribute to 20 or 30 more, until all have seed. Each farmer in effect becomes a secondary distribution center. Open pollinated corn varieties can be increased even more rapidly. But with the hybrid corns the farmers must go back each year to the original source to obtain seed possessing the hybrid vigor (see Figure 13.3). As a result, the adequacy of

Table 13.24. Comparative Data For Different Methods of Irrigated Corn Production. Bajio Region, 1960

	Fertilized-irrigated native (9)	*Fertilized-irrigated hybrid (15)*	*Nonfertilized-irrigated native (8)*	*Nonfertilized irrigated hybrid (3)*
Harvested area (ha)	386.5	366.5	97.0	18.5
Production (kg)	998,500.0	1,111,170.0	147,200.0	48,800.0
Yield (kg/ha)	2,583.4	3,031.8	1,517.5	1,688.3
Fert. Cost pesos/ha	438.68	296.27	—	—
Fert. Cost pesos/ton corn	169.80	104.40	—	—

Based on data of the Departamento de Economia Agricola, Instituto Nacional de Investigaciones Agricolas, Mexico.

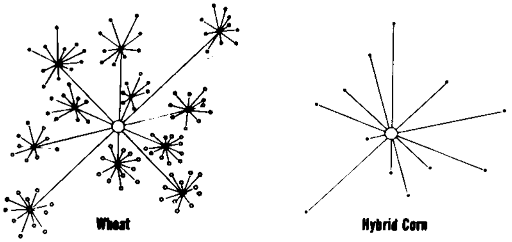

Figure 13.3. Seed distribution patterns

distribution depends heavily, in the case of Mexico, on a single seed multiplication agency.

The advantages of hybrid corn are based upon the hybrid vigor of specific crosses between selected genotypes. If the farmer replants this seed, he can expect a 15 to 20 per cent reduction in yield, giving a result only slightly better than that from an unimproved variety. This means that the double-cross hybrids needed to cover the different climates of Mexico must be produced anew each year, requiring an enormous seed multiplication and distribution network. Whether this network is made up of many private firms or is government-operated, as in Mexico, it must function at a high level of efficiency. It has basically two responsibilities: maintaining consistent high quality in the seed produced, and assuring that sufficient seed is readily available to all interested farmers.

On the first score, the task is to deliver to the farmer seed of the same quality and with identical yield potential as that produced originally by the plant breeder. This is not an easy task because of the complex seed-increase process involved in hybrid production.

The second problem is to make seed available to farmers in all parts of Mexico. Availability in this case must include price, location, timing—everything that makes the seed readily accessible to the farmer. The fact that a hybrid is available at certain times and places does not necessarily make it accessible to a small farmer without a vehicle who lives far removed from the seed outlets.

A more ample distribution network, combined with greater seed production, would undoubtedly result in greater use of hybrids. Yet if distribution has been a limitation on the benefits that Mexican farmers have realized from the corn hybrids, there are many extenuating circumstances. In fact, precisely because of this difficult distribution problem, the corn breeders are today working seriously toward the development of improved open-pollinated varieties with equivalent production potential. They feel now that in many of the developing countries it will be easier to change the breeding procedures than to attempt to surmount the difficult problems of multiplying and distributing hybrids. At some later time, when the greater development of various aspects of national economies permits adequate organization of hybrid seed increase and distribution, the gains obtained through varietal selection may serve as a basis for even more productive hybrids.

THE ROLE OF INFORMATION AND EXTENSION: ILLITERACY AND UNCERTAINTY

Even if measures are developed to cope with or to offset the important technical differences, there still remain the important problems of communication and extension of the new knowledge. What special information or extension activity is necessary to convince farm operators to make the desired changes? Obviously, in the first place the farmer must know of the existence of the new variety or new practice. He also needs other kinds of knowledge. He needs to know if the new varieties are adapted to his locality and his farm, and where he can buy seed and under what conditions. Beyond that, he needs specific instructions on cultivation practices in order to get the maximum good out of the new varieties.

In the case of wheat, where the growers were concentrated in a few rather well-defined areas, an important part of this work was undertaken by the research scientists. When a new variety was ready for increase, the breeders gave small quantities to both *ejidatarios* and private operators, but only under the condition that they would follow a strict set of cultural practices to guarantee a maximum increase and at the same time make a convincing demonstration for their neighbors. In this way the new wheat varieties served as a wedge to introduce a whole package of new practices, the most important of which were adequate fertilization and water management. The experiment station personnel have also taken the initiative to reach farmers through well-organized field days and through yearly publication of four regional bulletins, giving specific recommendations on varieties and cultural practices. These, in turn, have usually been reprinted in full in regional newspapers. In addition, the dramatic increases in yield which were obtained caused the message to spread by word-of-mouth. No large-scale extension effort was needed to bring about the yield increases that we have seen in wheat.

In the case of corn, the research workers have also participated in experiment-station field days, published regional farmers' bulletins, and collaborated closely in training extension agents. The Mexican government set up an emergency plan in 1954 to stimulate corn production in the Bajio, and this was expanded into a national extension program in 1955. Within recent years this national extension program has taken the initiative in promoting corn production campaigns in the major corn-producing states of Jalisco and Veracruz. This initiative, tying together technical assistance with credit and easier availability of new inputs, such as improved seed and fertilizer, is generally considered to have had creditable results. However, because of the variability of natural rainfall the impact is hard to measure, as can be seen in Table 13.25. If we take 1964 as our basis of comparison, Jalisco looks especially good; if we take 1963, Veracruz looks much better. When compared to 1957, both gained more than the national average in 1963, but Veracruz gained less in 1964. Tentative data for the past three years appear to indicate greater gains in Jalisco.

If we look specifically at the corn hybrids, we must conclude that they have not played the same key role as the improved wheat varieties, which were essential as insurance against the attack of stem rust. The corn hybrids have performed an important supporting role in attaining the maximum return from relatively heavy investment in fertilizer.

Whatever the progress up to now, it is clear that the problem of communicating with the numerous decision-makers who grow corn is much greater than for wheat. Although in certain irrigated areas many of the same farmers grow both corn and wheat, on the average the corn producer is a quite different person than the wheat producer. A general indication of this can be obtained from the 1960 population census. In the state of Sonora, which produces very little corn

Table 13.25. Comparison of Corn Yields for Jalisco, Veracruz, and Mexico for Selected Years 1940–1964[a] (in kilograms per hectare)

	Jalisco	Veracruz	Mexico as a whole
1940	549	1,050	626
1950	731	1,069	791
1957	1,052	1,085	835
1958	916	958	828
1959	1,250	1,158	880
1960	1,378	1,214	975
1961	1,464	1,085	993
1962	1,450	1,086	997
1963	1,340	1,590	946
1964	1,683	1,432	1,113
1965	1,679	1,600[b]	1,124
1966	1,828	1,650[b]	1,090
1967	2,046	1,650[b]	1,204
Percent Increase			
1957 to 1963	127	147	113
1957 to 1964	160	132	136
1950 to 1964	230	134	143
1940 to 1964	307	136	181

[a] The 1940 and 1950 data are from the National Census. Yearly data are from the Direccion General de Economia Agricola.
[b] Preliminary data, Direccion General de Economia Agricola.

and nearly three-quarters of the wheat, 66.5 per cent of the rural adult population (20 years and over) is literate. By contrast, in the two main corn producing states, Jalisco and Veracruz, literacy among the rural adult population is only 36.0 and 43.4 per cent, respectively.

In other areas where the rainfall varies around the bare minimum needed to produce a crop, the corn producers have a similar level of education. The data for the farmers without irrigation in Table 13.26 is indicative. Whereas there is no illiteracy among the farmers who operate more than 10 hectares of irrigated land, 44 per cent of those who operate only under natural rainfall conditions can neither read nor write. Incidentally, all of the farmers in this sample grow corn, and 86 of the 103 grew it every year during the 1950–1960 decade.

In spite of these deficiencies in formal schooling, all but nine of the farmers knew about hybrid corn. Nevertheless, of the 94 who were aware of hybrid corn, only 41 had planted it. At first glance this looks promising, as we know that farmers usually go through several steps in the adoption process, including: (1) initial knowledge of the practice; (2) acceptance of the practice as a good idea; (3) testing of the practice on their own land; and (4) full adoption of the practice once they are convinced of its usefulness. It appears that we have a large group in steps 1 and 2 who may soon become adopters. In fact, there is some support for this interpretation in the following chart (Figure 13.4) showing the number of persons who planted hybrid in each of the past ten years [Reding, 1963].

In spite of the slow increase, this does look like the beginning of a typical S-shaped adoption curve. Some doubt, however, is cast by the large number of persons who have planted hybrid on their own land and then discontinued its use after supposedly forming an opinion on its adaptability to their particular farms. In 1960 this group represented 41.5 per cent of all who had planted hybrid. This group will probably also have its influence on those who have not as yet tried hybrids.

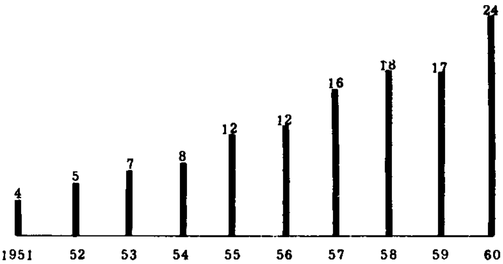

Figure 13.4. Number of farmers who planted hybrid corn from 1951 to 1960. Sample of 103 private operators in four municipios near Celaya, Gto.

Those who have used hybrids continuously since the first time they tried them are also frank in listing disadvantages, such as complaints about the condition of the seed that they purchase; however, they insist that the advantages more than compensate. The principal advantage that they list is higher yield, followed by others, such as that it matures more evenly and has more uniform plant and ears, better drought resistance and better tolerance of excess water, has a better market, heavier grain, commonly produces two ears per stalk, does not lodge, has less plants with no ears, and so forth.

There is no strong indication here that illiteracy or other impediments to the flow of

Table 13.26. Comparison of Educational Levels of a Sample of Farm Operators According to Size of Acreage Irrigated

		(ACREAGE IRRIGATED)			
EDUCATION OF FARM OPERATOR	*None*	*10 ha or less*	*10.1 to 50.0 ha*	*50.1 ha or more*	*Total*
Illiterate	22	4	0	0	26
Learned by himself or only a few months in school	11	8	3	4	26
1 to 4 years schooling	11	5	7	4	27
5 years or more	6	1	6	11	24
Total	50	18	16	19	103[a]

[a] Sample of private farm operators in four municipios near Celaya, Gto.

knowledge are holding back corn yields. The most basic limitation is the uncertainty of both the quantity and the distribution of the rainfall.

In the earlier Table 13.23 we saw that 78 natural rainfall plantings with 1,221 hectares of corn produced less than one-fifth as much as the 868.5 hectares in 35 irrigated plantings. In this type of area with serious rainfall limitations, it is doubtful that corn production will ever be a profitable enterprise, even with the best foreseeable drought-resistant varieties. Yet farmers continue to plow and plant each year, with no investment except their own labor and seed, in the hope that this year will bring good rainfall and a good harvest. Obviously this is not where the yield increases are going to be made; but until these farmers find better alternatives for their labor, they will continue to plant corn. For this group, cultivation practices and yields will not be greatly influenced by whether or not there is good communication of information.

Even in the areas with more adequate rainfall, it is likely that the slow adoption of improved practices is related more to the uncertainty and risks involved than to lack of information about existence of new practices. The success of extension programs will likely depend heavily on the degree to which they help the farmer reduce the risk which he faces in trying something new [Myren, 1964].

An attempt has been made to evaluate the impact of new technology on corn and wheat yields in Mexico over the past two decades. In comparing the many aspects that have influenced yields at the farm level, it has been possible to focus on a number of factors that have determined relative success at different points. It is hoped that this type of comparison may begin to lay the groundwork for a set of more general guidelines or principles for future programs aimed at raising the levels of crop production.

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Note: This article was written in 1965 and brought up to date in 1967; thus it does not include data on the Puebla Project, initiated in 1967. For a description of it, see *The Puebla Project 1967-69: Progress Report of a Program to Rapidly Increase Corn Yields on Small Holdings.* CIMMYT, Mexico, 1969.