THE RATE AND SEQUENCE OF ADOPTION OF IMPROVED CEREAL TECHNOLOGIES: THE CASE OF RAINFED BARLEY IN THE MEXICAN ALTIPLANO

By

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Working Paper 82/4

Preface

From 1971 to 1976 the CIMMYT Economics Program sponsored a series of adoption studies on wheat and maize technologies, particularly variety and fertilizer, in six countries. The results of these studies emphasized the importance of the agroclimatic and socioeconomic circumstances of farmers in explaining adoption patterns. Where nonadoption occurred, it was usually found that the technology was not consistent with farmer circumstances; that is, adoption was more a function of the characteristics of the technology than characteristics of the farmer, such as age, sex, education and extension contacts, which had been emphasized in previous adoption studies.

The current study strengthens these conclusions by bringing together new and different sources of data from a region in which CIMMYT has been working over the last five years. Data from on-farm experiments over several years enable more precise measures of technological characteristics, such as profitability and risk. Time series data from a random sample of farmers provide unique information on farmers' adoption patterns over a five-year period. Finally, instead of analyzing adoption of one component alone, such as variety, the present study jointly considers a series of both biochemical and mechanical technological components in which the effect of interactions among technological components is also analyzed.

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Acknowledgments

We are grateful to Edgardo Moscardi for the use of data from a farm survey he conducted in 1975 in which detailed records of names and addresses of farmers and locations of their field enabled us to easily resurvey the same farmers in 1980. We also appreciate the excellent cooperation from the CIMMYT Wheat Training Program, especially Paul Marko, Hikmat Nasr and Ron Knapp, who have conducted the on-farm experimental program from which data are extracted for the analysis in this paper.

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Introduction

In efforts to understand the process of agricultural development, economists and other social scientists have invested substantial resources in literally hundreds of studies of the adoption of new agricultural technolgies. Recent reviews of these studies (Rogers, 1976; Byrnes, 1982; Feder, 1981) indicate that despite this large amount of research, there remain three major deficiencies in our empirical knowledge of the adoption of agricultural technologies. First, most adoption studies have had a "pro-innovation" bias that assumes that the innovation is "right" and that patterns of adoption therefore relate to the socioeconomic characteristics of the farmer. However, the extensive series of adoption studies completed by the CIMMYT Economics Program highlighted the fact that major differences in adoption of technologies usually arose from variation, sometimes subtle, in the agroclimatic environment (Perrin and Winkelmann, 1976). Farmers rejecting the technology were acting quite rationally because the technology was not suitable for their particular circumstances. The only farmer characteristic that consistently appeared as important in the CIMMYT studies was farm size and, even here, there was evidence that after an initial time lag, small farmers usually adopted the same technologies as larger farmers.

A second deficiency is that adoption studies have been of a "snapshot nature", based on data on adoption and nonadoption at one point in time. Of the studies reviewed by Rogers (1976), only six percent used time series information; yet adoption is by nature a dynamic process that occurs over time. The failure to recognize this, led early studies of the adoption of new wheat varieties of the so-called Green Revolution to conclude that large farmers benefited more from the new technology. Later studies have shown that small farmers generally followed large farmers in accepting the technology (Byerlee and Harrington, 1982).

Finally, adoption studies have usually focused on only one innovation among a set of practices used for growing a crop (Feder, 1981). At the same time, agricultural researchers and extension agents have typically promoted a "package" of practices consisting of a number of technological components. Proponents of the "package" approach argue that a package captures the positive interactions between several components. On the other hand, because of capital scarcity and risk considerations, farmers are rarely in a position to adopt complete packages. Moreover, there is evidence that packages can often be disaggregated into pieces or "clusters" (Mann, 1977) of one or two components which allow critical interactions to be exploited and enable adoption to follow a sequential pattern with elements initially adopted providing the highest rate of return on increments in capital expenditures (Ryan and Subrahmanyan, 1975). This question of single technological components versus packages is important since it has implications for the way experiments are designed, as well as for the recommendations promoted to farmers.

This paper aims to interpret the rate and sequence of adoption of an array of technological components followed by farmers in barley production in the Altiplano of Mexico. The emphasis is on interpreting rates and sequence of adoption in terms of the characteristics of the technology, such as profitability, risk and divisibility, rather than such characteristics of the farmers as age, education and extension contacts, which have dominated previous adoption studies. An unusually rich data base enables us to treat some of the major deficiencies in previous adoption studies. A total of eight technological components including both mechanical and biochemical technologies are analyzed. Adoption of these technological components is traced over a five-year period, since surveys have been conducted with the same random sample of farmers in both 1975 and 1980. During this same five-year period, an extensive series of on-farm experiments has been conducted in the area, which provides good information on the performance of many of the technological components and their interactions under farmers' conditions. Finally, the study area is characterized by considerable variability with respect to agroclimatic factors and farm size, both found to be important in interpreting different rates of adoption of agricultural technologies in the earlier CIMMYT studies by Perrin and Winkelmann (1976).

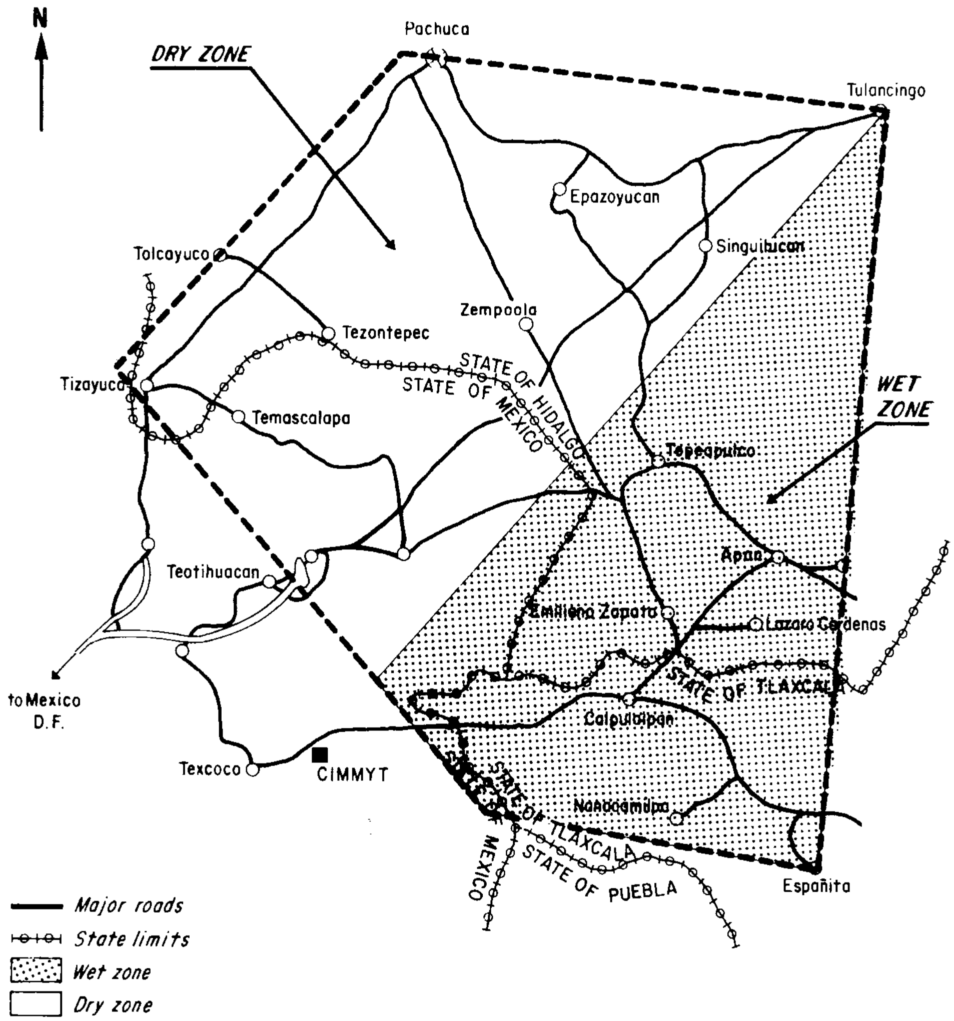
The sequence of adoption of technological components in small grains (wheat and barley) in drier areas with relative labor scarcity, such as the Mexican Altiplano, is also of particular interest because of the somewhat conflicting evidence currently available. Bolton (1979), an agronomist, hypothesizes an adoption sequence that emphasizes biochemical technologies, especially weed control followed by fertilizer, to more efficiently utilize available moisture. It is assumed that tillage methods to conserve moisture depend on tractor mechanization and will be adopted more slowly. Yet evidence from the drier areas of Turkey (Mann, 1982), Jordan (El Hurani, 1980) and Algeria (Masson, 1981) all suggest that tractor mechanization of initial tillage operations using (in many cases) rented tractors, precedes the use of biochemical technologies. However, most agree that changes in agronomic practices will be initially more important than varietal changes in drier areas (Byerlee and Winkelmann, 1981).

The analysis in this paper is developed in the following order. After a brief description of the study area and data collection methods, we construct a list of technological characteristics that we hypothesize to be important in farmers' adoption decisions. Evidence from on-farm experiments in the study area is used to rank technological components according to these characteristics and hence predict the rate and sequence of adoption. We then use longitudinal farm survey data to examine actual adoption patterns in light of these predictions and interpret the rate and sequence of adoption among the array of technological components. This also enables us to draw conclusions about the effects of interactions between technological components and the question of technological pieces versus packages.

Sources of Data

In 1975, CIMMYT's Wheat Training Program began an on-farm research program in the Mexican Altiplano for the purpose of training agronomists in rainfed wheat and barley production. The study area, shown in Figure 1, consists of parts of the States of Hidalgo, Mexico and Tlaxcala, that are within about one hours' drive from CIMMYT Headquarters and where barley is an important crop.

Figure 1. Map of the Study Area



In 1975 a survey was conducted with the objective of gathering information on barley production practices as a basis for designing on-farm experiments on barley and wheat in the study area. A total of 54 randomly selected farmers were interviewed in this survey.[1/] These same 54 farmers were revisited in 1980 and data collected on the same pro-

1/ Since no complete lists of farmers were available, these farmers were chosen by randomly identifying points on a map of scale 1:50000. These points were located on the ground and the farmer working that field identified and interviewed. This sampling procedure led to some bias toward large farmers who have larger fields and/or a larger number of fields and hence statistics presented at the regional level are biased toward large farmer practices.

duction practices and where possible for the same field.[1/] These surveys are unique in enabling a longitudinal tracking of farmers' practices over a five-year period of rapid change in the area. Data quality in each survey is high. Experienced research assistants from CIMMYT conducted the 1975 farmer interviews under close researcher supervision. In 1980, we conducted or were present in nearly all the interviews. However, the sample size is small in relation to the variability in the area.

In 1979, another survey of 87 farmers was carried out in only the southeastern and wetter parts of the study area in the valley of Calpulalpan and Apan. The main objective of this survey was to gather more detailed information and understanding of farmers' practices and problems in order to help plan experiments of the Wheat Training Program in this area. Results of the survey are described in Byerlee, Harrington and Marko (1981). In this survey, farmers were asked the year in which they first used selected new practices. Because of the larger sample size and greater detail, information from this survey is used to supplement the results of the longitudinal results.

An on-farm experimental program has been a major component of CIMMYT's production agronomy training program since its beginning. On-farm experiments in the study area generally consisted of research and verification experiments. These experiments have focused on the major agronomic problems of barley, i.e. variety, fertility (mostly nitrogen and phosphorous), weeds and stand establishment. For the purpose of this study, the results of 106 experiments over a five-year period have been analyzed to obtain response data on improved practices under farmer conditions. The experiments, however, were concentrated in the wetter zone, so disaggregation into rainfall zones sometimes leaves relatively few observations in the drier zone.

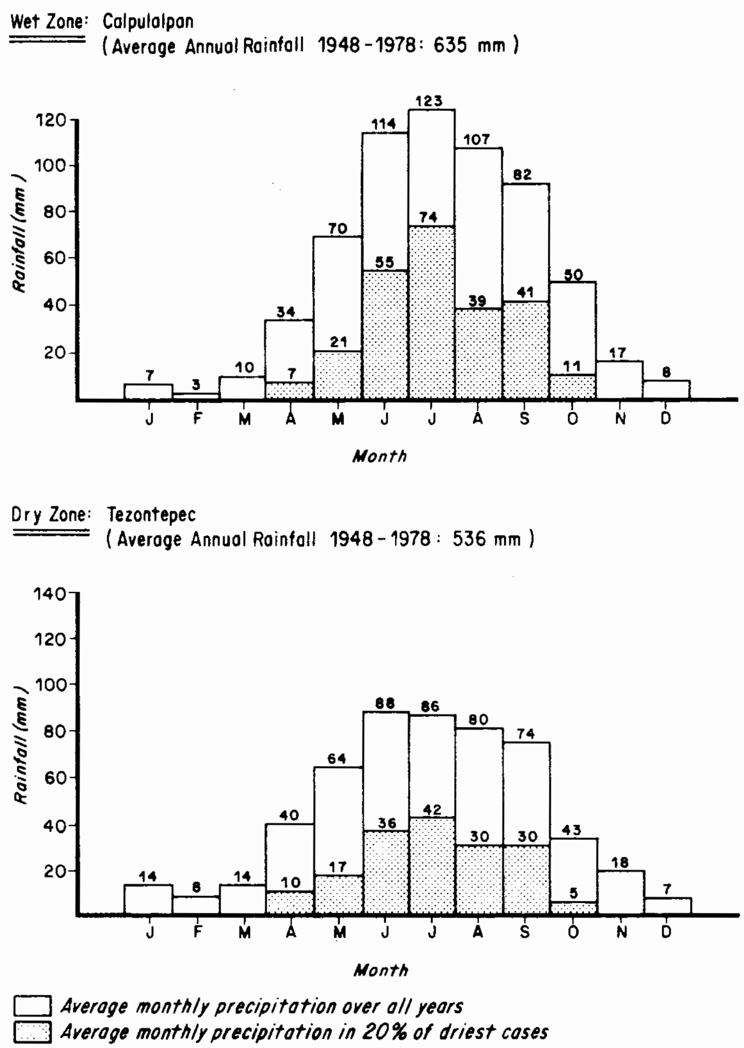
[1/] In two cases, the selected field was worked by a different farmer, and in a few cases maize was planted in the selected field, so questions were asked about the barley production practices in one of the farmers' other fields. In eight cases, the farmer did not plant barley in 1980, so that final sample size in 1980 was reduced to 46 farmers.

Farmer Circumstances in the Altiplano

Agroclimatic Circumstances

The study area is characterized by considerably heterogeneity in agroclimatic circumstances of farmers. These same circumstances also vary considerably from year to year, creating substantial risk to farmers. Annual average rainfall varies from less than 450 mm in the western part of the study area to more than 700 mm in the southeastern part. Based on rainfall data and experience obtained in five years of experimentation, the study area was divided into wet and dry zones. Rainfall distributions for representative sites in each zone are shown in Figure

Figure 2. Histogram of Monthly Rainfall Distribution for Sites in Each Rainfall Zone



Source: Unpublished data from Servicio Meteorológico Nacional, México

2. In the dry zone, rainfall is both lower and less reliable. On the basis of on-farm experimental results, we estimate that in this zone farmers suffer total or almost total crop losses one year in five. In the wet zone, this probability falls to one year in twenty.

With an average altitude of over 2500 meters above sea level, the length of the growing season in the study area is also constrained bv the incidence of frosts in the latter part of the season (September and October). This means that late planted barley (late June) that matures in 120-125 days runs a significant risk of frost damage.[1/]

The region can be further disaggregated into flat and sloping land. On sloping land there are severe erosion problems. The planting of the perennial cactus "maguey" on the contour is one measure used to reduce erosion damage. In this case, barley is interplanted among maguey rows, but narrow inter-row distance often prevents or complicates mechanization of operations.

Socioeconomic Circumstances

Major crops grown in the study area are barley, maize and maguey. Maize is the subsistence crop and relatively little is marketed. Barley is the cash crop. Two distinct markets exist for barley--for forage and for malting. Traditionally, most barley was produced for animal forage, either for the farmer's own animals or for sale.[2/] However, as the demand for beer in Mexico has increased rapidly throughout the 1970s, much more barley is now produced for malting purposes, especially given the location of the area near large breweries in Mexico City.

Farm size and land tenure arrangements vary considerably over the study area. Small farmers with less than 20 hectares predominate; these tend to hold land under the ejido system of the land reform program although there are also some small private farmers. Larger farmers with

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1/ Normally, rainfall is sufficient to allow earlier planting, but farmers who delay planting after opening rains to control weeds or for lack of machinery, run the risk of early frost.

2/ Data from the 1970 Agricultural Census indicate that approximately 60 percent of barley was produced for forage purposes in the wet zone, and nearly all barley produced in the dry zone was for forage.

over 20 hectares of land control a substantial share of the total cropped area. These farmers own land privately and the largest farmers (over 100 hectares) often rent additional land.

Several features of the economic environment are important to understanding technological change in the study area. Barley prices, influenced by the increasing demand for malting quality barley and the higher proportion of barley sold for malting purposes, have risen relative to competing activities. From 1975 to 1980, prices received by farmers for barley increased by over three times, compared to a doubling of maize prices and a 162 percent increase in the consumer price index. At the same time, real wage rates have increased by about 20 percent in response to alternative opportunities in the nonagricultural sectors in the area (including an industrial complex at Sahagun and a state capital at Pachuca), as well as in the nearby Mexico City labor market.[1/]

Sources of Improved Technologies

Several institutions have a role in promoting improved technology in the area. A private organization of major breweries, Impulsora Agrícola, has promoted barley production for malting purposes, especially among large farmers, in several ways: (1) through distribution of improved varieties of higher malting quality, (2) by providing technical advice, and (3) by acting as a buying agent. The official credit bank also requires as part of its loan the use of a package of inputs that usually includes an improved variety, herbicide and fertilizer. There is an extension service, although its primary activity is to provide technical advice through the official bank. They do not have a demonstration program, nor is there a research program operating in the area to provide recommendations to farmers. [2/] However, there is no doubt that the CIMMYT on-farm research/training program, through its on-farm experiments and demonstrations, has also had some impact on the spread of new

1/ Real wage rates were calculated by deflating money wages by the official consumer price index.

2/ INIA, the national agricultural research institute, has successfully developed improved barley varieties, but has done relatively little research on management practices for the area, especially under farmers' conditions.

technologies, even though its major objective has been training. Finally, farmers themselves have been a major source of innovation. Many large farmers have contacts with farmers in more advanced irrigated areas in other parts of the country, or even contacts abroad, and bring back new ideas and inputs for experimentation.

Characteristics of the Technological Components and the Predicted Adoption Pattern

A Model for Analyzing Adoption Decisions as a Function of Technogical Characteristics

In this study, we emphasize the characteristics of the technology as they affect the pattern of adoption. A technology is the aggregate of all practices or technological components used to grow a crop. A practice or technological component is defined by the time, method and intensity of a particular operation in crop production. For example, a practice for weed control with herbicide is defined by the type, method, rate and time of application of the herbicide. The adoption pattern of a particular technological component can be defined by the time of initiation of adoption and the rate of adoption once initiated. Given a series of independent technological components with no interaction between the components, we hypothesize the adoption pattern to be defined by five characteristics of the technological component: a) profitability, b) riskiness, c) divisibility or initial capital requirements, d) complexity, and e) availability.[1/]

Profitability, defined here as return to investment in a given technological component, is expected to be an overriding factor in farmers' adoption decisions. Farmers with capital constraints will adopt that practice giving highest returns to available capital. However, adoption of a profitable technology is expected to be slower if it increases risks. Divisibility of the technnology measured in terms of initial cash costs may also affect rates of adoption patterns--large farmers are expected to adopt less divisible inputs before small farmers.

1/ Byrnes (1982) hypothesizes similar but not identical characteristics consisting of observability, comparability, profitability, reliability and trialability.

Technological components requiring more management complexity may require a longer time to diffuse as farmers build up sufficient experience to capture potential returns from using the technology. Finally, all these factors are modified by the availability of inputs, equipment and information for each technological component, which in turn is a function of such institutional factors as the relative role of the private and public sector in providing inputs and information to farmers.

Profitability and riskiness of a component are themselves a function of elements of the agroclimatic and socioeconomic environment, such as rainfall and prices. Moreover, heterogeneity in the farm population is likely to lead to a slower rate of adoption because of differences in risk aversion, management capacity, information and capital availability among farmers in the population. Farm size, which has been identified as an important variable in previous adoption studies (e.g. Perrin and Winkelmann, 1976; Feder, 1981), is a proxy for many of these factors.

Finally, interactions between technological components will affect adoption patterns. Where positive interactions exist, the adoption of one technological component is expected to accelerate the adoption of additional components. In the extreme case, where inputs are perfect complements, all technological components would be adopted as a package since no one component would function without the presence of the others.

Overview of the Technological Components Analyzed

A total of eight different technological components are examined in this study. Table 1 compares the "improved" method with the "traditional" method. These improved practices have been divided into mechanical components and biochemical components. Following Hayami and Ruttan (1971), the mechanical components are labor saving while the biochemical components are yield increasing or land saving. Hence, we expect a somewhat different adoption pattern depending on relative factor prices. Also, it is generally assumed that mechanical technologies favor large farmer adoption, while biochemical technologies are essentially scale neutral and, given equal access to input and product markets, can be equally well adopted by either small or large farmers.

Table 1. Comparison of Different Elements of the Traditional and Improved Technologies

	"Traditional" Technology	"Improved" Technology
Mechanical Components		
1. Land Preparation		
a. Power source and implement for initial tillage	Animal with wooden or steel plow	Tractor with disc plow or subsoiler
b. Intensity of tillage prior to planting	One tillage operation and sometimes none	Ploughing combined with one or more harrowings
c. Timing of initial tillage	After rains begin in April/May	After the previous harvest in October to January
2. Planting	Broadcast and covered by tillage implement	Use of seed drill
3. Harvesting	Cutting by hand[a] and threshing with animal or stationary thresher	Use of combine harvester
Biochemical Components		
1. Variety	"Comun" a variety introduced by the Spanish in the colonial period	Apizaco, Cerro Prieto and other varieties released by the Mexican research institute (INIA) since 1965
2. Weed Control	None or some hand weeding	Use of back-pack sprayer to apply 2,4-D herbicide to control broadleaf weeds
3. Fertilizer	None or use of some organic manure	Application of nitrogen and sometimes phosphorous fertilizer.

[a] A few farmers also employed an intermediate harvesting technique, using a horse or tractor drawn "stripper" to cut and then to transport the barley to a mechanical thresher. This practice is not analyzed in this study.

Characteristics of the Mechanical Technological Components

The mechanical components examined in this study essentially represented the replacement of animal or human power by motor power. There is considerable evidence that the cost of motor power is substantially cheaper than their animal- or human-powered counterparts. By 1980, the cost per hectare of renting animals for ploughing was double the cost of renting a tractor, and this did not include the cost of labor or forage in using rented animals. Likewise, in 1980 the cost of hand harvesting was more than double the cost of mechanical harvesting by combine (Table 2). Even assuming hand harvesting is performed by lower cost family labor (which is not usually the case), hand harvesting still requires the use of a stationary thresher, which is only marginally cheaper than a combine harvester.

The use of the drill to replace hand-broadcasting of seed is the only mechanical technology in which there is no real cost advantage, largely because little labor is employed in hand-broadcasting; about 0.5 person-days/ha is required compared to at least 5 person-days/ha for hand harvesting.

There is also considerable evidence that the cost of mechanization has declined over time. The real cost of tractor ploughing and combine harvesting in terms of grain equivalents [1/] has decreased by about 20 percent over the period 1975 to 1980 (Table 2). The increased competition to provide rental services arising from an increased number of machines, a steadily increasing subsidy on fuel, and a favorable sales tax and import duties for agricultural machinery, have been factors in this declining real cost. Over the same period, the cost of labor in grain equivalents has remained steady,[2/] indicating a fall in the relative costs of mechanical practices.

1/ Because we are using price and cost data from two points in time in a period of rapid inflation, we have converted money costs to grain equivalents using field prices of barley of $1.3/kg in 1975 and $4.1 in 1980.

2/ As mentioned earlier, the real wage rate calculated by deflating money wages by the consumer price index has risen by 20 percent.

Table 2. Costs of the Mechanical Technological Components in 1975 and 1980

	Year 1975	Year 1980	Percent Change 1975 to 1980
	(kg of grain equivalent per ha)[a]		
Animal rental for ploughing	n.a.	220	n.a.
Tractor rental for ploughing	153	122	-21
Tractor rental for harrowing	77	61	-21
Rental of drill	n.a.	73	n.a.
Rental of combine	230	195	-16
Hand harvesting (with labor cost)	531	497	-6
Hand harvesting (without labor cost)	223	192	-14
	(kg of grain equivalente per day)		
Unskilled wage rate per day	31	30	-3

[a] Based on field price of barley of $1.3/kg in 1975 and $4.1/kg in 1980.

n.a. not available.

These cost differences might be modified if there are yield effects of the mechanical technologies, especially since a switch to tractor power also involves a change in tillage implements. Because the on-farm experimental program emphasized biochemical technologies, we do not have complete evidence on yield effects. Eight experiments were carried out over the period to compare broadcasting and drilling. Broadcasting outyielded drilling by 8 percent, but the difference was not significant. However, drilling does allow large farmers with limited labor to plant in a more timely manner.[1] Two experiments were also conducted on additional tillage operations in 1979 and 1980 and showed an average yield increase of 315 kg/ha to one additional harrowing. This is similar to an estimated yield response of 280 kg/ha derived from an analysis of farmers' yields in 1979 (Byerlee, Harrington, Marko, 1981). These yield increases compare very favorably to an estimated cost of 60 kg/ha in

[1] In the 1979 survey, farmers with over 20 ha planted an average of one week earlier if they used a drill.

grain equivalents for the additional harrowing.

The other characteristics of the mechanical technologies--riskiness, divisibility, complexity and availability--depend largely on the type of farmer. For a large farmer who purchases his own tractor, we expect divisibility to be a problem, but risk may be reduced since more timely operations are possible.1/ However, complexity is increased because of the need to manage and maintain the equipment. For small farmers who adopt by renting machinery, divisibility is overcome and there is no problem of increasing complexity, since the farmer rents the operator as well as the machine. However, availability and riskiness may be a problem, since in a limited rental market, farmers may have to queue for machinery services. There is evidence that tractor renters perform less timely operations than owners because of the difficulty in obtaining a tractor when moisture conditions are appropriate for tillage or planting (Byerlee, Harrington, Marko, 1981). However, it is expected that as the rental market develops and a larger number of tractors becomes available, these problems should be reduced.2/

Characteristics of the Biochemical Technological Components

Characteristics of each biochemical component are shown in Table 3 and Figure 3. Profitability and riskiness of the technological components have been calculated from the results of the on-farm experiments conducted from 1976 to 1980. Calculations in Table 3 do not consider interactions, which are analyzed separately in the following section. We have disaggregated the analysis into wet and dry zones, because the results are quite sensitive to rainfall.3/

1/ Risk may be reduced by increased moisture conservation in dry years through earlier tillage and better weed control prior to planting. Drilling may also enable better placement of seed in relation to moisture in a dry seed bed.

2/ Until recently, machinery services in the area have been entirely the province of the private sector. Now, the official credit bank is also giving loans to groups of small farmers for machinery purchase.

3/ For example, average yields in the variety experiments in the dry zone were 1.60 ton/ha with a coefficient of variation of 55 percent compared to average yields of 2.45 ton/ha and a coefficient of variation of 27 percent in the wet zone.

Rates of return to investment, as a measure of profitability, were calculated following the methodology of Perrin et al. (1976). Full details and assumptions are given in Appendix A. Of the three biochemical components, improved variety gives the highest rate of return on investment in both rainfall zones. This arises despite the fact that average yield increases from using improved varieties were only 11 percent in the wet zone and 3 percent in the dry zone. However, the cost of changing variety is low, since seed may be kept over several years. Also the major factor leading to high profits from using newer varieties has been the development of a market for barley of malting quality. This has led to an average price premium for improved varieties of 10 percent over prices received for the local variety, which has poor malting quality. Returns to improved varieties are particularly high in the wet zone.

Herbicide, and then fertilizer follow variety in terms of profitability in the wet zone, where both give significant increases in yields. Herbicide gives particularly high returns at 1980 prices in the wet zone where weed problems are more severe. At 1975 prices, herbicide use was only marginally profitable in the dry zone, but because of a decline in real prices should be attractive to farmers in 1980. Similarly, returns to fertilizer use have increased dramatically from 1975 to 1980, reflecting a 44 percent decline in the real price of nitrogen fertilizer measured in grain equivalents. The higher return to fertilizer use in the dry zone reflects a lower optimal fertilizer dose,[1/] a smaller number of observations, and the dominance of two unusually high yielding sites.

The distribution of yields over sites and years in the experiments was used to calculate two measures of risk in each rainfall zone for each biochemical component. In both cases, it is assumed that risk averse farmers are concerned about consequences at the lower end of the distribution of economic benefits, i.e. the worst results. First, the absolute risk from using the new component was calculated by the gain or loss in grain equivalents for the lowest 20 percent of the distribution

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1/ The optimal dose in the dry zone was estimated to be 45 kg/ha of nitrogen, compared to 80 kg/ha of nitrogen in the wet zone.

Table 3. Characteristics of the Biochemical Technological Components in 1975 and 1980

	Improved Variety [a]		Herbicide		Fertilizer [b]	
	Wet Zone	Dry Zone	Wet Zone	Dry Zone	Wet Zone	Dry Zone
Average yield increase (kg/ha) [c]	254*	43	282*	118	598*	451*
Marginal rate of return on investment (percent/year)						
1975	1419	411	281	77	91	163
1980	2172	667	430	146	223	444
Risk Measure I (kg/ha grain equivalent gained or lost in 20% worst cases at 1980 prices)	122	-19	87	-17	-15	-113
Risk Measure II (estimated probability that net benefits of improved technological components are less than those of traditional technological components at 1980 prices)	6	36	13	22	13	33
Initial cash costs (kg/ha grain equivalent)						
1975	231		86		276	162
1980	183		52		160	96

* Significantly different from check treatment at 5 percent level.

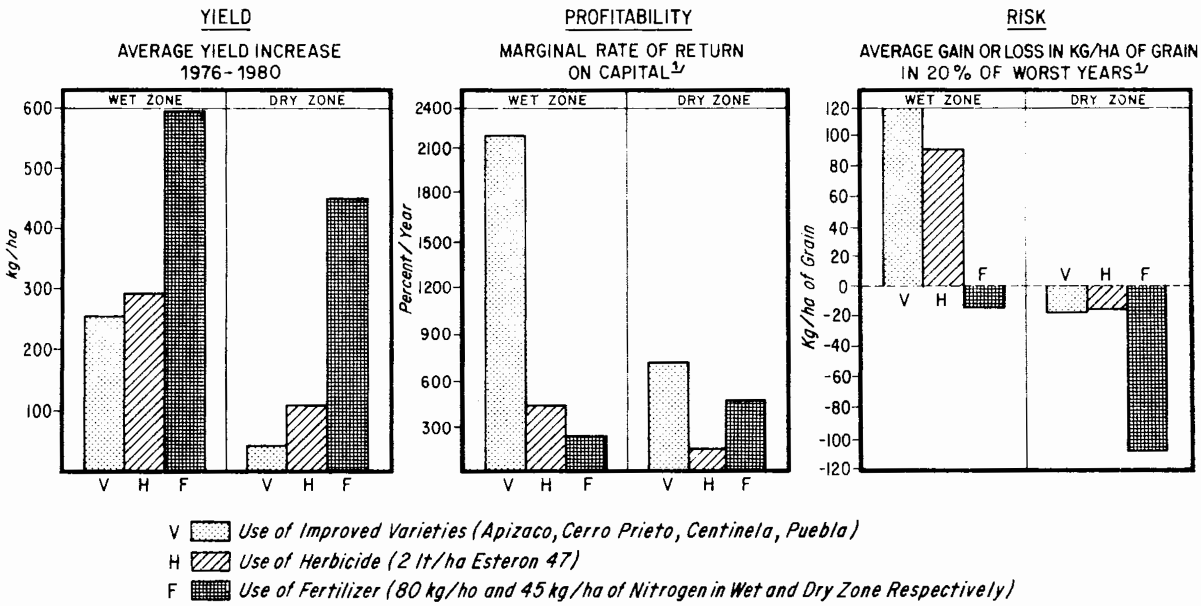
[a] Refers to purchase of certified seed. Seed from other sources (e.g. neighbors) usually costs less. In addition, it can be used over a five-year period.

[b] 80 kg/ha of nitrogen in the wet zone and 45 kg/ha of nitrogen in the dry zone.

[c] Calculated taking into account lost sites.

Source: Based on on-farm experimental data, 1976 to 1980 (see Appendix B).

Figure 3. Comparison of Yield Increase, Marginal Rate of Return on Capital and Risk of the Three Biochemical Technological Components



1/ Calculated at 1980 prices

Source: Based on results from on-farm experiments, 1976-80

as in Perrin, et al. (1976). Second, we calculated the incidence of risk by estimating the percentage of years in which farmers would experience an economic loss (i.e. negative returns on capital) for a given change in technology when compared to the traditional practice.[1/]

In the case of variety, there is virtually no risk from using improved varieties in the wet zone and only a very small risk in the dry zone--whichever risk measure is used. In the dry zone, the local variety gives higher returns in over one-third of the years but, because the

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1/ In each case the distribution of yields over many experiments and years is assumed to represent true year to year variation faced by farmers. In practice, the distribution also includes site to site variation which we have reduced but not eliminated, by stratifying by rainfall zone.

cost of changing varieties is not high, the absolute risk is not high.[1/]

Herbicide was not considered risky in the wetter zone. Herbicide gave positive returns in the wet zone even for the 20 percent worst results. However, in the dry zone, because the incidence of crop loss is about one in five, use of any input is risky. Even so, absolute losses from herbicide use in the dry zone are not high because of its low cost. Moreover, since herbicide is applied one month after planting, the farmer can reduce risks by not applying if the crop shows poor early development.

Finally, fertilizer is by far the most risky of the inputs considered, although losses are small in the wet zone. In the dry zone, fertilizer use (at a lower dose of 45 kg/ha of nitrogen) is risky even for the worst 33 percent of the results and expected losses in the driest years are over 100 kg/ha in grain equivalents.

In terms of initial capital costs, the lowest cost change is for herbicide use, provided a back-pack sprayer is rented. A capital outlay of only about 50 kg/ha in grain equivalent was necessary for adoption of herbicide in 1980. The initial cost of using an improved variety depends on the source of seed. If certified seed is used, initial costs are quite high. However, most farmers who do not work with the bank purchased seed from friends and neighbors at substantially lower prices. Fertilizer use at recommended doses is the most costly change, but like the other biochemical inputs, it is divisible and hence initial adopters with scarce capital can use lower doses.

1/ Also for variety, stability parameters were calculated for the six most commonly used varieties in the study area following the method of Eberhard and Russell (1966). Yield of individual varieties was regressed on the mean yield of all varieties at that location. A slope of the regression line greater than one indicates relatively better response to good conditions, while the intercept indicates the response under poor conditions. A high R^2 indicates wide adaptation. The local variety Común and the improved varieties, Apizaco and Cerro Prieto, had a slope of less than one, while the new early varieties, Centinela and Puebla, show greater response to better environments. The local variety also shows the widest adaptability, as indicated by the high R^2, while Centinela shows quite variable performance. This often arises because a dry spell during the growing cycle does not allow this early variety to recover. By these measures, Común, Apizaco and Cerro Prieto are less risky varieties and in fact, were the most widely grown varieties in 1980.

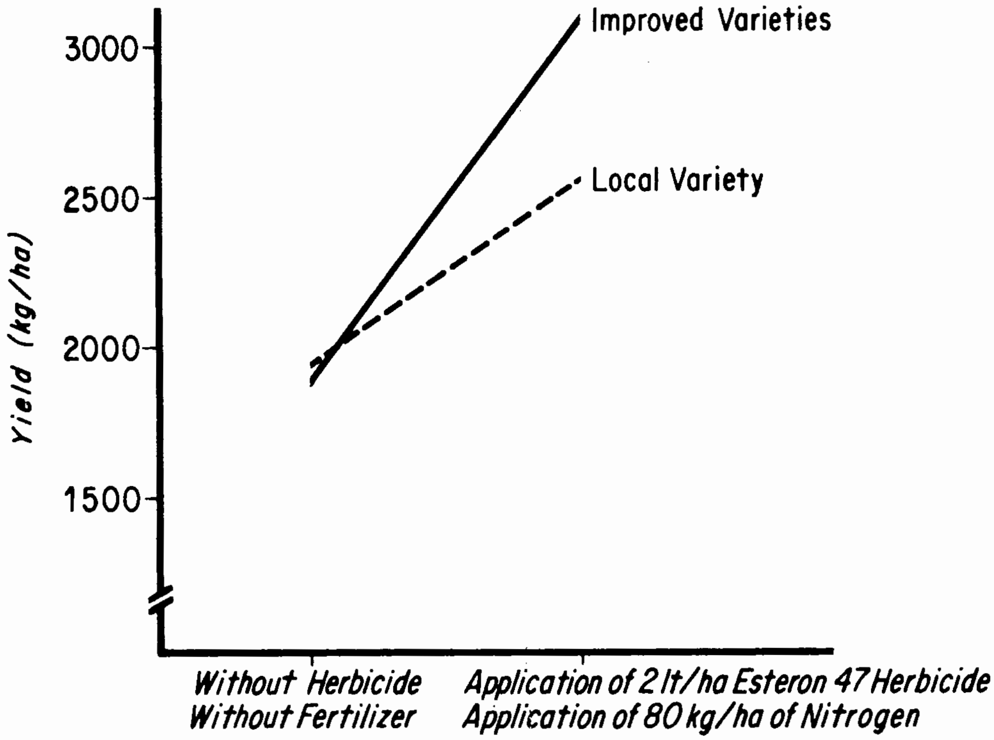
Variety is also the least complex of the changes, providing there are no strong variety by management interactions (see next section). Seed of the new variety is simply substituted for that of the old variety at the same seed rate. Fertilizer and herbicide both require calculations of dosages per unit of area and judgements on the appropriate time of application in relation to crop development and climatic conditions. Fertilizer represents an additional complication in the study area because of the number of different products with varying nutrient composition, which requires that farmers have some knowledge of nutrient needs and the ability to calculate dosages. On the other hand, only one herbicide product is commonly used on barley.

Finally, the availability of the different inputs varies. Both seed for improved varieties and herbicide are available in private stores or "veterinarias". Moreover, a farmer working with the official credit bank is usually obligated to use improved seed provided through the bank. Fertilizer, on the other hand, is only available through the official credit bank or government owned stores. Distribution points were few and stocks of fertilizers erratic, so farmers using fertilizer had to travel a considerable distance to obtain supplies.

Interactions Between Technological Components

Some limited evidence is available on the interaction between variety, herbicide and fertilizer. Five experiments have been conducted on variety by management with local and improved varieties being tested with and without the application of fertilizer and herbicide. Results are shown in Figure 4. At low management levels, there was no difference between local and improved varieties. At high management levels, the improved variety gives significantly higher yields, since the local variety tends to lodge with the application of nitrogen fertilizer. A further variety by weed control interaction arises in the market for malting quality barleys that are discounted for weed seed impurities. This further raises the return from herbicide weed control in improved varieties.

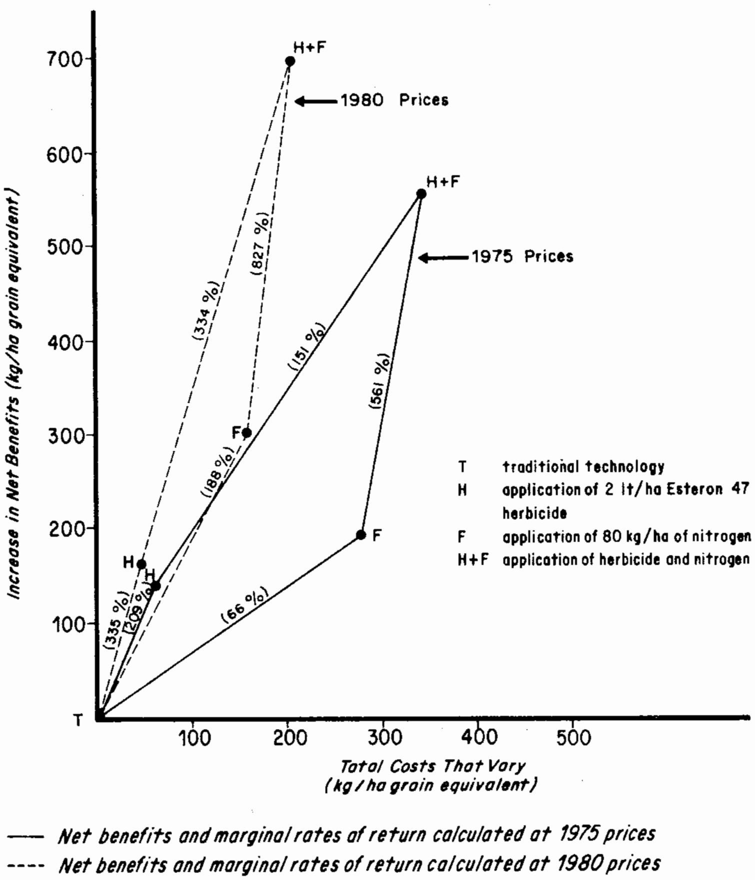
Figure 4. Variety by Management Interactions in the Wet Zone



Source: Calculated from data from 5 on-farm experiments during 1976-80

Twelve experiments have been conducted on fertilizer by herbicide use, mostly in the wet zone. As expected, there was positive interaction between herbicide and fertilizer. Marginal rates of return analysis shown in Figure 5 strongly indicates the sequence of adoption to be herbicided followed by fertilizer. The addition of herbicide alone costs little and provides high returns. The addition of fertilizer alone, however, gives much lower returns and was only marginally profitable at 1975 prices. Figure 5 also indicates the extent to which real costs of adoption of biochemical technologies have fallen since 1975.

Figure 5. Net Benefit Curves Showing Interaction of Herbicide and Fertilizer in the Wet Zone at 1975 and 1980 Prices[a]



[a]Numbers in brackets are marginal rates of return on investment

Source: Calculated from data from 9 on-farm experiments during 1976-80

Predicted Adoption Sequence

In sum, there is substantial evidence that factor price relationships favor rapid mechanization of land preparation and harvesting but not drilling. Yield effects of additional tillage operations and probably of earlier tillage, are also associated with tractor use for land preparation. However, adoption patterns are likely to be strongly influenced by farm size, as larger farm size favors machinery ownership. Small farmers who adopt by renting machinery should lag in their adoption of machinery, especially if rental services are provided by larger farmers. Finally, we expect adoption of mechanical components to be influenced by topography, since large machinery can be used more efficiently on flat open land. In the study area, the interplanting of barley and maguey on sloping land complicates the use of machinery.

Among the biochemical components, the evidence on rates of returns, risk, complexity, and availability all points toward an adoption sequence of variety followed by herbicide and then fertilizer, at least in the wet zone. Note that yield increases run in the reverse order from about 600 kg/ha for fertilizer to only 250 kg/ha for variety in the wet zone (Figure 3). Data on interactions between these components also suggest adoption in the same order to enable exploitation of high marginal returns on initial capital expenditures. Although there are positive interactions between herbicide and fertilizer, these inputs can be adopted separately with strong indications in the wet zone that it will be more effective to adopt herbicide before fertilizer.

We are not able to analyze interactions between the biochemical and mechanical technological components. However, three observations are relevant. First, the inital cost of mechanical components when adopted by renting are not high in relation to the biochemical components, especially at 1975 prices. However, the initial cost of the biochemical components in terms of grain equivalents has fallen by 30 percent for herbicide and 44 percent for fertilizer, compared to 20 percent for mechanical components. Hence, we expect more rapid adoption of biochemical components in later years. Second, we expect complementarity between moisture conservation practices, such as early tillage and additional secondary tillage, and the use of such biochemical components as improved varieties and fertilizer. Finally, the use of yield-increasing biochemical components is likely to place a premium on mechanical harvesting, in which costs are relatively insensitive to yields.

Analysis of Farmers' Actual Adoption Patterns

Two measures of adoption were used in this study. First, farmers were asked about the use of a given practice in the year of the survey. This provides a longitudinal measure of adoption of specific technological components in 1975 and 1980. This measure may underestimate adoption if a particular practice was not used in the survey year because of climatic or other reasons. Second, we asked farmers if they had ever used a given practice and if so in what year they first used this practice. This measure could overstate actual adoption since some farmers may have adopted and then rejected a practice. In fact, we rarely encountered this in the survey.

Both measures of adoption were used to analyze adoption patterns in a two-step procedure. First, given the substantial variability in farmers circumstances encountered in the area, we wanted to divide farmers into more homogeneous subgroups for the analysis of adoption patterns. Logit analysis of actual use of a practice was employed for this purpose. Second, the time of initiation of adoption and the rate of adoption of each technological component for each subgroup was estimated by fitting a logistic curve to data based on farmers recall on the year of adoption. Parameters of these logistic curves were then used to compare adoption patterns across technological components for each farmer subgroup.

Logit Analysis of Major Factors Affecting Adoption

To delineate subgroups of farmers, we used a logit analysis to relate adoption of each technological component to major variables explaining different agroclimatic and socioeconomic circumstances of farmers.[1/] These variables were rainfall, topography, farm size and sometimes use of bank credit. We have already seen from the analysis of the on-farm experiments that rainfall has an important effect on returns and risk from using the biochemical technological components. Topography has been identified as important in other adoption studies (e.g. Perrin and Winkelmann, 1976) probably as a proxy for information and market access, since hilly areas are generally less well served by roads and are further from market centers. Also, mechanization is expected to be less efficient in hilly areas where the intercropping of barley with maguey is practiced. Farm size has been another important variable in many adoption studies. It may be a proxy for a number of factors, such as economies of scale of use of new technologies (particularly mechanical technologies), economies of scale in acquiring information, ability to take risks, and access to capital and inputs. In dividing by farm

1/ With a bivariate dependent variable (i.e. two values representing nonadoption and adoption) error terms are biased in a standard regression. Logit analysis with maximum likelihood estimation following Nerlove and Press (1973) overcomes this problem.

size, we followed an earlier study that showed that farmers with less than 20 ha depended largely on the rental of tractor services, while larger farmers owned tractors (Byerlee, Harrington, Marko, 1981). Finally, the bank often provides inputs in kind, and hence bank credit is expected to influence adoption, especially of biochemical components.

To get maximum discriminating power in the logit function, we chose that survey (1975 or 1980) for which the adoption level of the component was closest to 50 percent. That is, the 1975 survey data were analyzed for tractor, combine and variety and the 1980 survey data were used for drill, herbicide and fertilizer. A logit function was then run for each technological component using nonadoption/adoption as the dependent variable, and rainfall, topography, farm size and sometimes bank credit as the independent variables.

Results of the logit analysis are presented in Table 4. In the case of mechanical components, except for the drill, topography had the largest effect on adoption levels. The combine is still not used on almost half of farms in sloping areas regardless of farm size. Farm size significantly influenced the adoption of tractors and drills. Only in the case of a drill does rainfall significantly affect the adoption of a mechanical component.

As expected, rainfall generally had the largest effect on the adoption of all three biochemical components. Farm size affected the adoption of variety and fertilizer but did not significantly influence herbicide use. As hypothesized, bank credit influenced the adoption of variety and also affected fertilizer adoption at the 10 percent level of significance.

Logistic Curves of Adoption Patterns

Logistic curves of cumulative adoption levels over time were fitted to analyze the adoption path of each farmer subgroup for each technological component. The logistic curve is defined as:

$$A_t = K/(1 + e^{-c-\phi t})$$

where A_t is the cumulative percentage of adopters by time t, K is the

Table 4. Estimated Logit Function of Adoption for Six Technological Components [a/]

	Tractor	Combine	Drill [b/]	Improved Variety	Herbicide	Fertilizer
Survey Year	1975	1975	1980	1975	1980	1980
Number of Observations	54	54	45	53	46	45
Farm Size						
(0: ≤ 20 ha)	.34	.13	.27	.29	.14	.49
(1: > 20 ha)	(2.69)*	(1.32)	(2.60)*	(2.36)*	(1.18)	(2.53)*
Rainfall						
(0: dry)	-.02	.02	.26	.40	.38	.41
(1: wet)	(.26)	(.24)	(2.87)*	(3.03)*	(3.53)*	(2.53)*
Topography						
(0: slope)	.37	.34	.002	.21	.10	.28
(1: flat)	(3.52)*	(3.93)*	(.02)	(1.84)	(.97)	(1.82)
Credit Use						
(0:non-user)	--	--	--	.33	--	.28
(1: user)				(2.58)*		(1.82)

* Significant at the 5 percent level; numbers in parenthesis are asymototic t-ratios.

[a/] Estimated change in the probability that a farmer will adopt given a one unit change in the independent variable, using the logit estimation procedure of Nerlove and Press (1973).

[b/] The equation for drill is estimated by ordinary least squares because some independent variables take only one value for adopters, making logit estimation impossible.

upper bound on percentage adoption,[1] ϕ is the rate at which adoption occurs and c is the constant term. This curve (see Figure 6) was chosen because the cumulative adoption path for new technologies generally follows a similar S-shaped path (Griliches, 1957). The number of adopters increases slowly at first because only the most progressive and/or less risk-averse farmers adopt. Then it increases more rapidly as other farmers become aware of the advantages of this technological component and finally slows down as all farmers who find the component profitable have adopted. The ceiling, (i.e. 100 percent of adoption) might not be reached or could be reached rather slowly (Jarvis, 1981).

Using the logistic curve, the adoption pattern can be described by two parameters from each curve shown in Figure 6. First, we calculated A, the year in which 20 percent of the farmers had adopted a given practice. This was arbitrarily chosen as a measure of the time of initiation of adoption to represent a point where a significant number of farmers had already adopted.[2] Second, we determined BC, the number of years required for 50 percent of the farmers to adopt the practice during the period of most rapid adoption.

The logistic curve was fitted to each subgroup of farmers depending on the factors identified in the logit analysis as affecting adoption of a specific practice at the 20 percent level of significance. Where topography and farm size both affected adoption (i.e. tractor and variety), the sample was divided into large farmers (over 20 ha, most of which are on flat land), small farmers in flat areas and small farmers in sloping or hilly areas. This was necessary because of the positive association

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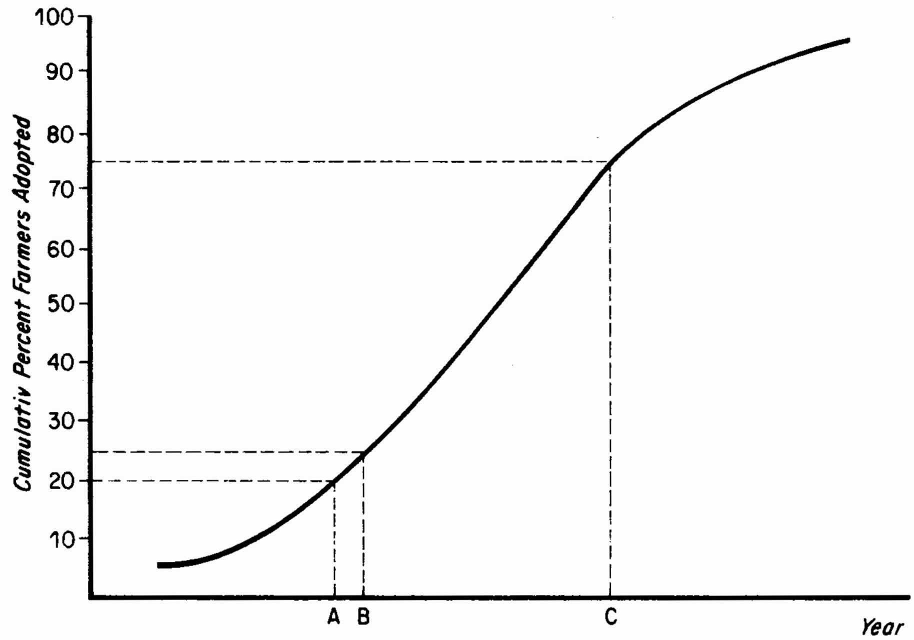
1/ K may vary depending on the expected terminal adoption rate. In our case, all technological components (with the possible exception of the drill) are expected to be completly adopted in the long run because of their profitability and hence 100 percent adoption was assumed.

2/ Because the logistic curve is asymptotic to the X-axis, it is not possible to estimate the time of initiation of adoption directly.

Figure 6. Logistic Function Representing the Adoption Process



A: Initiation of the adoption process (i.e. 20 percent of farmers have adopted)

BC: Number of years in which 50 percent of farmers adopt during the period of fastest adoption

between farm size and flat land.[1/] No such association was found between rainfall and topography or rainfall and farm size.

Parameters for the logistic curves are given in Table 5. In addition, the actual use of the practice in 1975 and 1980 is reported.[2/] Looking at the time of initiation of adoption for the whole sample, it is evident that except for the use of a seed drill, mechanical technological components have been adopted before all three biochemical components. However, the rate of adoption for mechanical components is generally slower than for the biochemical components, indicating the greater divisibility of the biochemical components. By 1980, the ranking of

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1/ The sample size in the 1975 and 1980 surveys is too small to allow a breakdown of large farms by topography. 83 percent of the large farmers operated on flat land.

2/ Differences between the two sets of results arise from the different definitions of adoption noted above, as well as possible uncertainty on the part of farmers about the year in which they first used a practice.

Table 5. Parameters of the Logistic Function and Actual Adoption Levels in 1975 and 1980

	Parameters of Logistic Function		Actual Use of Practice		
	Time of Initiation of Adoption	Rate of Adoption	Percent of Farmers		
	(Year in which first 20% farmers adopted)	(Number of years required for middle 50% of farmers to adopt)	Used in 1975	Used in 1980	Ever used in 1980
Mechanical Components					
Tractor					
All farmers	1957.6	13.4	59	91	96
Large farmers	1948.7	12.6	89	100	100
Small farmers/flat land	1959.0	9.6	70	100	100
Small farmers/slopes	1967.5	9.6	12	82	88
Combine					
All farmers	1967.2	8.6	59	80	80
Large farmers	1963.8	4.6	78	100	100
Small farmers/flat land	1966.7	6.7	70	94	94
Small farmers/slopes	1973.9	n.a.	25	50	50
Drill					
All farmers	1981.6	16.3	6	13	15
Large farmers	1970.0	n.a.	17	33	33
Biochemical Components					
Improved Varieties					
All farmers	1969.1	12.3	51	76	76
Large farmers	1967.6	5.6	78	100	100
Small farmers/flat land	1964.0	11.2	53	94	94
Small farmers/slopes	1977.2	n.a.	19	41	41
Wet zone	1964.0	9.6	76	91	96
Dry zone	1975.6	5.4	29	61	61
Herbicide					
All farmers	1971.9	9.7	43	44	50
Large farmers	1966.7	n.a.	56	67	67
Small farmers	1972.2	8.9	36	38	44
Wet zone	1968.2	7.2	77	74	82
Dry zone	1978.4	n.a.	11	13	17
Fertilizer					
All farmers	1971.6	11.4	28	41	54
Large farmers	1963.9	11.7	44	92	92
Small farmers/flat land	1971.2	6.5	25	41	65
Small farmers/slopes	1977.5	n.a.	13	6	24
Wet zone	1969.2	10.3	46	62	65
Dry zone	1975.4	6.5	14	26	30

n.a. not analyzed because of too few observations.

adoption for the whole sample was tractor, combine, variety, herbicide, fertilizer and drill. This is almost identical to the ranking of adoption levels in the 1975 survey.

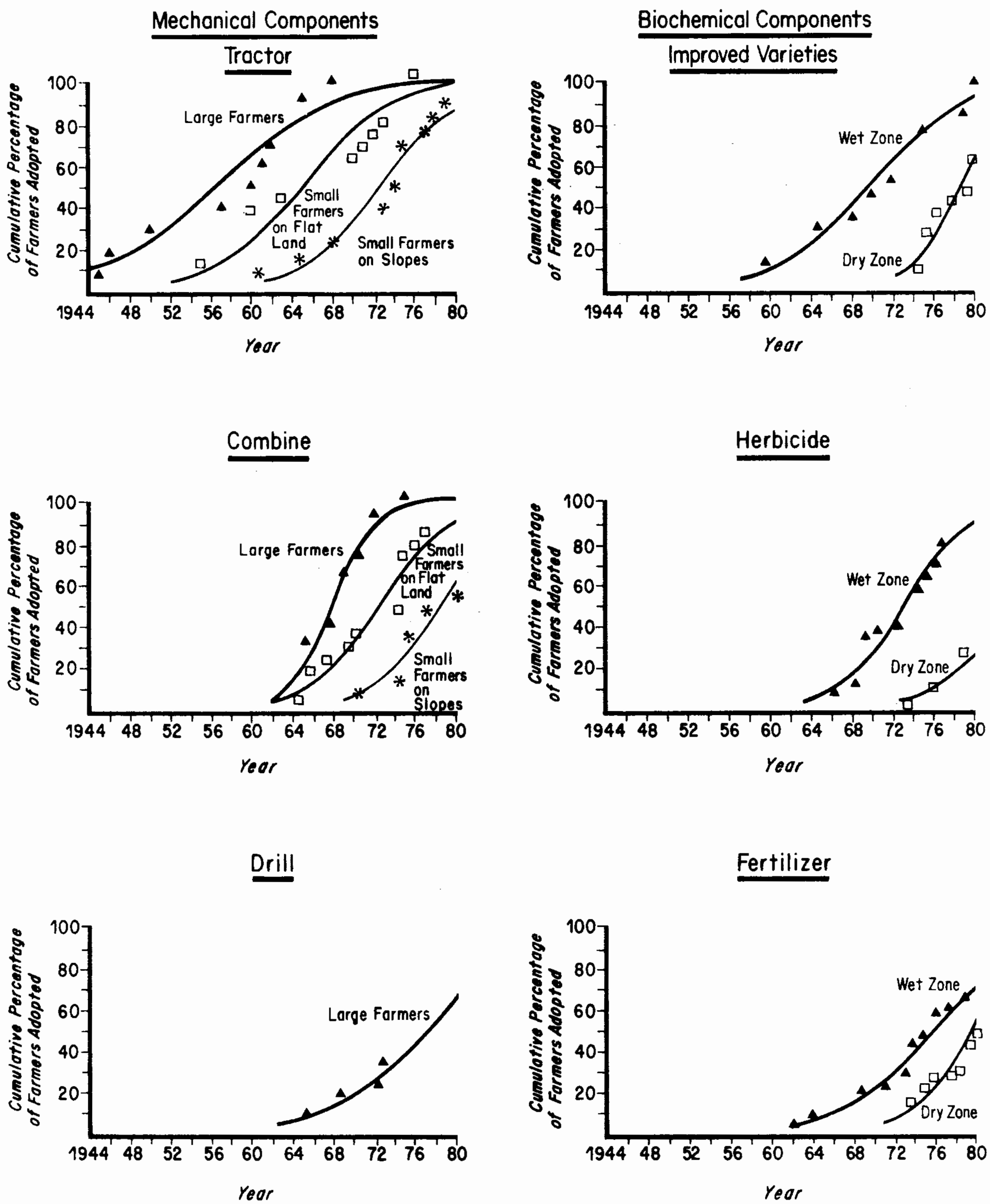
Adoption Path for Mechanical Technological Components

Tractor use for land preparation was the first component adopted and preceded combine harvesting by about 10 years. Among both tractor and combine users, early adopters were large farmers on flat land, followed by small farmers on flat land and, finally, small farmers on sloping land. This last group lagged large farmers in adoption by 19 years for tractors and by 10 years for combines (see Figure 7). It is particularly significant that early users of tractors (i.e. large farmers) generally adopted by purchasing a tractor. In both 1975 and 1980, 75 percent of large farmers using tractors were tractor owners. Later adopters are almost entirely renters of machinery services. For example, all but one farmer who changed from animal to tractor power between 1975 and 1980 adopted through tractor rental. On sloping land, this enabled tractor use among small farmers to increase from 12 percent in 1975 to 82 percent in 1980--a particularly rapid rate of adoption even compared to large farmers.

Adoption of combines on sloping land was also very rapid, reflecting the high cost of hand harvesting. Again, all farmers who changed from hand harvesting to combines from 1975 to 1980 adopted by rental. Many large farmers also adopted combine harvesting through rental--only 42 percent of large farmers owned a combine harvester in 1980. The rental market for combines has also been strengthened by the development of a national rental market in which combine harvesters from other parts of Mexico are imported to the area at harvest time. Interplanting of barley with maguey has prevented the complete change-over to combine harvesting and kept the adoption rates lower than for tractors. Many farmers, however, are removing some maguey rows to increase inter-row spacing and facilitate combine harvesting.

Associated with the adoption of tractors has been an increase in the intensity of tillage operations. More than twice as many farmers ploughed early after the previous harvest in 1980 compared to 1975 (Table 6). The number of tillage operations also increased slightly between

Figure 7. Logistic Curves for the Adoption of Six Improved Technological Components



Actual points used to fit logistic curves are represented by ▲ □ *

Table 6. Timing of Initial Tillage and Total Number of Tillage Operations by Power Source in 1975 and 1980

	Percent of Farmers Doing Early Initial Tillage [a]		Average Number of Tillage Operations	
	1975	1980	1975	1980
Animal Power	11	n.a.	1.7	n.a.
Rented Tractor	23	37	2.3	1.7
Owned Tractor	38	58	2.7	3.3
Whole Sample	22	51	2.1	2.3

[a] October to January.

n.a. not analyzed because of less than 5 observations.

1975 and 1980. In both cases there is a significant positive correlation between the intensity of tillage operations and the use of a tractor versus animal power. Also among tractor users, significantly more tractor owners plough early and undertake additional secondary tillage operations compared to tractor renters, as shown by Table 6. The increase in timing and intensity of tillage between 1975 and 1980 is due both to a switch from animal power to use of a rented tractor and an increase in tractor ownership. Twenty-seven percent of tractor renters in 1975 had become tractor owners by 1980 (Table 7).

Table 7. Changes in Source of Power Between 1975 and 1980

	Power Source in 1975			
	Animal Power	Rented Tractor	Owned Tractor	All Farmers
Power Source in 1980	(Percent Farmers)			
Animal Power (percent)	21	0	0	9
Rented Tractor (percent)	74	73	6	50
Owned Tractor (percent)	5	27	94	41
TOTAL	100	100	100	100

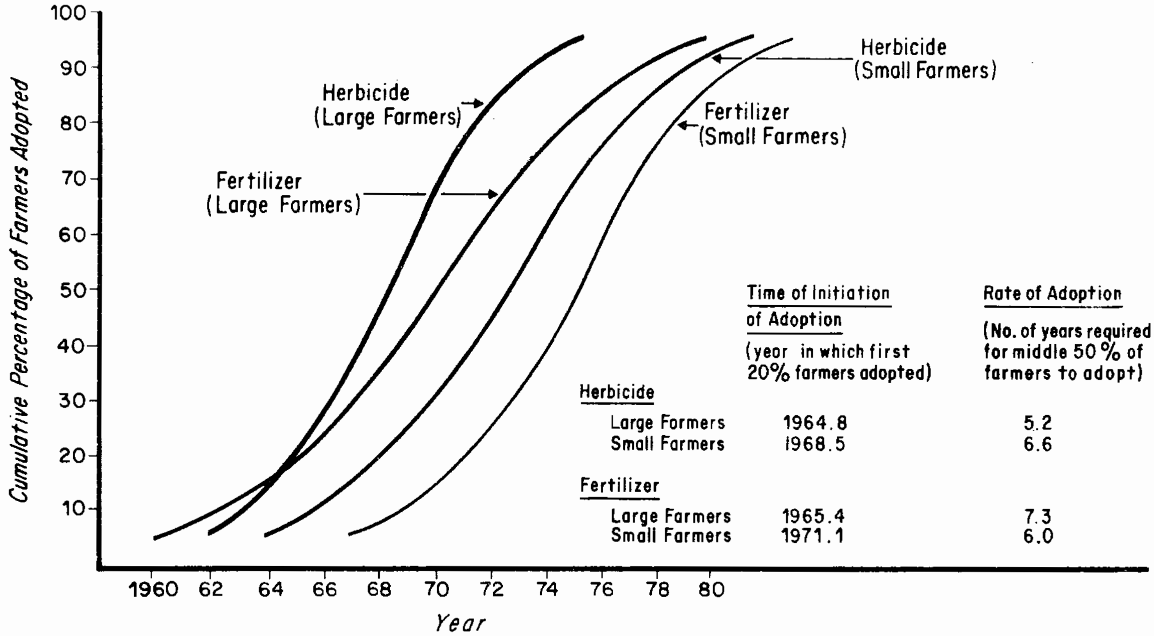
Finally, adoption of seed drilling in place of broadcasting lagged compared to the other mechanical components. By 1980, only 13 percent of farmers used a drill, and this was almost entirely confined to large farmers in wetter areas. This result is in agreement with our prediction that based on the low cost of hand broadcasting of seed, drilling would only be profitable for large farmers wishing to ensure timely planting.

Adoption Path for Biochemical Technological Components

Within the biochemical group of technological components, the use of improved varieties was generally the first practice to be adopted. However, its adoption lagged behind that of mechanical practices, particularly tractor use. By 1980, improved varieties had been adopted by nearly all farmers in the wet zone. Small farmers lagged large farmers in adoption, but the lag was less than in the case of tractor use. Improved varieties have also been adopted very rapidly in the dry zone, but with a substantial lag in initiation of adoption compared to the wet zone. In 1980, 61 percent of farmers used improved varieties in the dry zone compared to only 29 percent in 1975. These results accord with the data from on-farm experiments, which indicate that use of improved varieties is the most profitable and least risky of the biochemical components. Widespread adoption of improved varieties by both small and large farmers has also been aided by their relatively simplicity and low initial capital cost.

Use of improved varieties has been closely followed by adoption of herbicide and fertilizer, but the pattern is somewhat different between the wet and dry zone. In the wet zone, herbicide adoption leads the use of fertilizer and was also adopted more rapidly. As with other practices, large farmers adopted earlier than small farmers, although the lag is small in the case of herbicide. This is most apparent in the adoption pattern in the 1979 large sample in the wet zone shown in Figure 8. For both farm size groups, herbicide leads fertilizer in adoption. These results correspond to the higher returns, lower risks and lower initial capital costs of herbicide relative to fertilizer. The greater lag in the adoption of fertilizer by small farmers may reflect the problems of availability of this input.

Figure 8. Adoption Curves for Herbicide and Fertilizer for the 1979 Farmer Survey in the Wet Zone



In the dry zone, fertilizer has been more rapidly adopted than herbicide, although both practices were still used by a small proportion of farmers in 1980. The earlier adoption of fertilizer relative to herbicide in this zone does conform to results from the on-farm experiments, which indicate high but risky returns from fertilizer use relative to herbicide use. However, the small number of observations available from on-farm experiments and the low adoption rates prevent us from drawing definite conclusions. Furthermore, some farmers counted in the adoption curve had used fertilizer often within a package provided by the official credit bank, but were not using fertilizer in 1980.

Technological Packages versus Step-wise Adoption

From the on-farm experimental results, it appeared that although there are positive interactions between the biochemical components, these interactions should not prevent the adoption of each component in a step-wise manner, especially if farmers follow a sequence of variety-herbicide-fertilizer. In fact, in no case did a farmer adopt all three biochemical components in the same year and only about 20 percent of farmers adopted two components together--usually herbicide and fertilizer (Table 8). Furthermore, among farmers using all three components of the package, the average lag from adoption of the first to the last component was nearly five years.

Table 8. Adoption Sequence of Biochemical Technological Components for Individual Farmers in the Wet Zone

	1979 Survey	1980 Survey
Percent of farmers using at least one biochemical component who adopted:		
variety before herbicide and fertilizer	n.a.	68
herbicide before variety	n.a.	14
fertilizer before variety	n.a.	9
variety and herbicide in the same year	n.a.	5
variety and fertilizer in the same year	n.a.	0
herbicide and fertilizer in the same year	n.a.	18
all three biochemical components in the same year	n.a.	0
Percent of farmers using herbicide or fertilizer who adopted:		
herbicide before fertilizer	51	61
fertilizer before herbicide	23	17
fertilizer and herbicide in the same year	26	22

n.a. not available.

As indicated by the logistic curve, variety was the first component adopted in both the wet and dry zone. The on-farm experimental results indicated that positive interactions exist between variety, herbicide and fertilizer use, but that variety alone is still quite profitable, especially in the wet zone. In fact, 68 percent of farmers using at least one of the biochemical components had adopted variety first, usually independently of other biochemical components. The experimental results also suggested large positive interactions between fertilizer use and herbicide, but with a feasible adoption path of herbicide followed by fertilizer. Again, among farmers in the wet zone who had adopted fertilizer and/or herbicide, more than half used herbicide before fertilizer and less than one-quarter adopted both in the same year (Table 8).[1/] Two-thirds of the farmers who used both herbicide and fertil-

[1/] This sequence is not apparent in the dry zone, which also accords with the low level of interaction found in the on-farm experiments. However, we are reluctant to draw conclusions because of the small number of observations in the dry zone.

izer in the 1979 survey, and who adopted fertilizer first, followed within three years with the use of herbicide. Only one-third of farmers adopting herbicide first followed with fertilizer use in the same space of three years. The evidence then clearly points to a step-wise pattern rather than a package approach to adoption. Even with strong positive interactions between technological components, individual components can usually be identified that give high returns when adopted in a step-wise manner.

Conclusions

The present study has clearly documented the adoption pattern followed by farmers during a period of rapid technological change. During this period of 10 to 15 years, most farmers have mechanized the major operations of land preparation and harvesting and, especially in the wetter zone, adopted a package of biochemical technological components. Although the area may not be typical because of its proximity to Mexico City, which has influenced both the labor and product market, the example does illustrate the potential for rapid technological change with appropriate technologies and economic incentives.

The high and rising relative cost of hand and animal methods has been a major factor favoring rapid mechanization. The drill is the only mechanical component that has not been widely adopted, and this reflects the limited potential for saving labor costs by drilling relative to the other mechanical components.

Mechanization was first adopted by larger farmers on flat land. However, small farmers have adopted these technologies rapidly, especially tractors and combines, after a lag of several years. The active development of a machinery rental market has been a major factor in explaining high rates of mechanization among small farmers. In fact, 80 percent of small farmers adopted tractors before biochemical technological components, indicating that with development of a machinery rental market, mechanical components are highly divisible inputs. Topography, which decreases the efficiency of mechanization on slopes, especially where barley was intercropped with maguey, was generally a more important determinant of mechanization than farm size.

While the major motive for mechanization appears to be the saving of labor, tractor use in land preparation is also associated with yield increasing practices, such as early ploughing and increased secondary tillage. These practices increase with both the change from animal to tractor power and with the change from tractor rental to tractor ownership.

Adoption of the biochemical technological components is most strongly influenced by rainfall. Adoption in the dry zone, where economic returns were generally lower and risks higher, considerably lagged adoption in the wet zone. The adoption sequence among the three biochemical components strongly reflects the relative economic returns and risks to each component. In the wet zone, the sequence followed by farmers was variety-herbicide-fertilizer. Because high economic returns were closely associated with low risk components, it was not possible to separate the effects of profitability and risk. The order of adoption of the biochemical components is the reverse of the expected yield increase from each component.

Although there were strong positive interactions between all three biochemical components, few farmers adopted more than one component at the same time. Rather adoption followed a clear step-wise pattern with components giving highest returns on capital invested being adopted earliest. Hence, farmers over time and in a sequential manner will adopt the complete package of biochemical components.

The above findings have a number of implications for an efficient strategy for development and diffusion of improved agricultural technologies. First, the need to divide farmers into relatively homogeneous subgroups or recommendation domains for the purposes of research and extension is illustrated by the results--particularly the sharp distinction in economic returns, risk, and adoption rate of biochemical components between the wet and dry zones. However, definition of these recommendation domains needs to take a long-term perspective. In particular, after a time lag, small farmers usually followed the same adoption path as large farmers. The small farmer-large farmer dichotomy, often believed to require separate research strategies, may not be as important as commonly believed, at least for a commercial crop such as the case analyzed here. The early adoption by large farmers allows experience to be gained in the use of biochemical technologies by those best able to take risks. It also allows development of a machinery rental market for small farmers.

Second, although the research strategy might aim to develop a package of practices that exploits positive interactions between technological components, this package should be a goal for adoption over time and not for direct extension to farmers. Rather, the research strategy should seek a step-wise pattern of adopting components in such a way that each step is both profitable to farmers and appropriate to their capital constraints. The check plot in each experiment should reflect existing farmer practice or a projected farmer practice in the future. In this case study, herbicide trials would be conducted with improved varieties but without the application of fertilizer. Fertilizer trials to establish optimal levels of application would be conducted using both improved varieties and herbicide weed control.

Furthermore, the identification of research priorities should be based on economic analysis of the likely profitability of each component rather than potential yield increases. The common strategy of focusing on "yield constraints" or the "yield gap" would have emphasized research on fertilizer, which in fact was the last component to be adopted. Moreover, farmers apparently do not need to see large yield increases to be convinced about adoption of a practice. Improved varieties, which were adopted first over the whole study area, gave an estimated yield increase of less than 10 percent.

Finally, the private sector has been a major participant in the diffusion of technologies to farmers in the present case. The private sector, through machinery distributorships and entrepreneurial farmers, has largely introduced mechanization and has also, through the association of breweries, played a major role in promoting biochemical components at least to large farmers. However, the public sector, through the release of new barley varieties by the research system and the provision of inputs and credit by the official credit bank, has also been important. The public sector, by way of favorable pricing policies, has also provided strong incentives for technological change. However, we believe an effective on-farm research and demonstration program in the area, would have contributed significantly to refining recommendations and increasing the diffusion rate, especially to small farmers. Even now our on-farm research results indicate that most farmers could reduce or eliminate phosphorous application, and that the efficiency of herbicide use could be increased by more timely application.

Appendix A. Prices, Labor Requirements, and Input Levels Used in the Economic Analysis of On-Farm Experiments

	Prices 1975	Prices 1980	Labor Requirements and Input Levels
Barley Field Price ($/kg)	1.3	4.1	
Machinery Rental			
Animal power for ploughing ($/ha)[a]	n.a.	900	2 person-days/ha
Disc Plough ($/ha)	200	500	
Disc Harrow ($/ha)	100	250	
Drill ($/ha)	60	300	
Stationery Thresher ($/ha)[b]	290	788	
Combine ($/ha)	300	800	
Labor			
Wage Rate ($/day)	40	125	
Labor Costs and Requirements for:			
Hand broadcast ($/ha)	20	63	.5 person-day/ha
Herbicide application ($/ha)	20	63	.5 person-day/ha
Fertilizer application ($/ha)	20	63	.5 person-day/ha
Hand harvesting ($/ha)	400	1250	5 person-days/ha
Inputs			
Improved Seed ($/kg)	3	7.5	100 kg/ha
Herbicide:			
2,4-D as Esteron 47 ($/lt)	60	160	.7 lt/ha
Back-pack sprayer rental ($/day)	50	40	
Fertilizer:			
Urea ($/kg)	1.8	3.2	80 kg of N in wet zone 45 kg of N in dry zone
Transport ($/kg)	.15	.2	
Capital Cost (percent per crop cycle)	35	55	

[a] Two horses without labor and forage costs.

[b] Assuming an average yield of 1.7 ton/ha and including transport costs.

n.a. not available.

Appendix B. Summary of On-Farm Experimental Results, 1976 to 1980

	WET ZONE		DRY ZONE	
	No. of Observations	Mean Yield [a/] (t/ha)	No. of Observations	Mean Yield [a/] (t/ha)
Variety Experiments				
Local Variety	15	2.33 *	9	1.58
Improved Varieties		2.59		1.63
Herbicide Experiments				
Without Herbicide	15	2.08 *	7	2.18
With Herbicide[b/]		2.44		2.33
Fertilizer Experiments				
Without Nitrogen	22	1.92 *	12	1.58
With Nitrogen[c/]		2.54		2.14
Variety by Management Experiments	3		2	
Local Variety-Traditional Management		1.86		.99
Improved Variety-Traditional Management		1.83		.51
Local Variety-Improved Management[d/]		2.62 *		1.43
Improved Variety-Improved Management[d/]		3.15		1.12
Herbicide by Fertilizer Experiments	9		3	
Traditional Practice		1.67 *		1.12
With Herbicide[b/]		1.85		1.36
With Fertilizer[c/]		2.14 *[e/]		1.74
With Herbicide and Fertilizer[d/]		2.65		1.80
Seeding Method Experiments	8			
Broadcast		3.16		-
Drill		2.92		-
Land Preparation Experiments	2			
No disc harrowing		2.57		-
One disc harrowing		2.93		-
Two disc harrowings		3.20		-

* Significantly different from check treatment at 5 percent level.

a/ Does not include lost sites.
b/ Application of 2lt/ha of 2,4-D.
c/ 80 kg/ha of nitrogen in the wet zone and 45 kg/ha of nitrogen in the dry zone.
d/ Application of both herbicide and fertilizer as specified in footnote b and c.
e/ Significant differences also exist if herbicide alone and fertilizer alone treatments are compared to application of both herbicide and fertilizer.

Appendix C. Parameters of the Logistic Curve Estimated Estimated by Least Squares Regression

	Intercept	Coefficient	t-value	No. of Observed Years	R^2
Mechanical Components					
Tractor					
All farmers	-10.8	.164	21.26	21	.960
Large farmers	- 9.9	.175	8.36	9	.764
Small farmers on flat land	-14.9	.229	3.44	8	.663
Small farmers on slopes	-16.9	.230	18.09	10	.976
Combine					
All farmers	-18.5	.255	16.17	12	.963
Large farmers	-31.9	.478	8.69	7	.938
Small farmers on flat land	-23.3	.329	9.34	9	.926
Small farmers on slopes	-23.4	.298	3.95	5	.839
Drill					
All farmers	-12.4	.135	9.90	6	.961
Large farmers	-15.6	.203	12.38	4	.987
Biochemical Components					
Improved Varieties					
All farmers	-13.9	.181	14.40	12	.954
Large farmers	-28.1	.395	6.62	7	.898
Small farmers on flat land	-14.0	.197	7.56	10	.877
Small farmers on slopes	-24.3	.297	2.93	3	.896
Wet zone	-16.1	.230	9.45	8	.937
Dry zone	-32.3	.409	11.46	6	.970
Herbicide					
All farmers	-17.7	.227	9.78	12	.914
Large farmers	-13.2	.177	2.97	5	.746
Small farmers	-19.3	.246	12.55	9	.957
Wet zone	-22.2	.305	10.16	9	.937
Dry zone	-22.0	.263	38.42	3	.999
Fertilizer					
All farmers	-15.2	.193	14.17	12	.953
Large farmers	-13.4	.188	8.70	10	.904
Small farmers on flat land	-20.6	.270	12.57	6	.975
Small farmers on slopes	-32.3	.399	3.05	3	.903
Wet zone	-16.2	.214	18.73	10	.978
Dry zone	-26.8	.337	6.48	7	.894

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* Available in English and Spanish
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