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ECONOMICS PAPER

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Contents

Abstract

This study presents a methodology (in five steps) for assessing the impact of information and technologies generated by a crop management research (CMR) program. The methodology is demonstrated by estimating the return to CMR conducted in the Yaqui Valley of Mexico between 1977 and 1987. The overall rate of return to the investment in CMR was estimated to be 16% in real terms. This is somewhat lower than observed for other rate of return studies, partly because the entire portfolio of research projects, many of which were not productive for the period under evaluation, was evaluated. For integrated pest management (IPM) and ridge planting, the two successful research projects in the CMR program that produced the entire flow of benefits, the rate of return was in excess of 100% for IPM and about 45% for ridge planting. The fact that a considerable amount of CMR was apparently unproductive argues for more careful monitoring of farmers' acceptance of CMR results. Guidelines for the design and implementation of a program aimed at monitoring the impact of CMR on farmers' practices are provided.

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1

Introduction

Origins of This Study

The relationship between public agricultural research and changes in farm productivity has interested economists for more than three decades. However, the influence of one important area of agricultural research — crop management research (CMR) — on farm productivity has not received much attention. This kind of research can be defined as including practically all crop-related research not aimed at varietal development: research on crop husbandry (e.g., seeding rates, planting dates, and tillage methods); pest management (e.g., method and timing of weed and insect control measures); and resource management (e.g., irrigation scheduling).[1] This definition, which is used in the present study, is broad but conforms with those used in previous studies.[2]

The products of crop management and crop breeding research programs are fundamentally different. Crop breeding primarily consists of applied research aimed at generating new varieties. Crop management research may be adaptive and applied (adaptive research generally dominates), and its principal product is information on better practices.

This difference in products means that different methods are required to evaluate the impacts of each kind of research. Methods for evaluating the impact of crop breeding research are well established, and studies that have estimated the returns to varietal development have generally found them to be high.[3] However, no consensus exists on how to measure the returns to crop management research, nor are estimates of the likely magnitude of these returns available. Information on expenditures for CMR is fragmentary, but the estimates available (Table 1.1) suggest that about half of all research resources in the public sector are spent on CMR. Given this level of expenditure, more effort should be made to measure the impacts of CMR. Therefore, this study focuses on the question: How do we measure the impact of CMR in the public sector on agricultural productivity?

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1 Sometimes CMR is equated with agronomic research. The definition applied here is somewhat broader since it includes farm management research related to the design and evaluation of improved production practices.

2 For example, Anderson, Herdt, and Scobie (1986:220) refer to "methods and programs other than plant breeding" and to "non-germplasm technologies" in their discussion of "crop husbandry and research methods." Sanders (1988) uses a similar definition.

3 See Griliches (1957) for hybrid maize in the United States, Akino and Hayami (1975) for rice in Japan, Nagy (1984) for wheat and maize in Pakistan, Ardito Barletta (1971) for wheat and maize in Mexico, Zentner (1985) for wheat and rapeseed in Canada, Ayer and Schuh (1972) for cotton in Brazil, and Hertford et al. (1977) for rice in Colombia.

The relatively few *ex-post* evaluations that have been undertaken examined only narrowly targeted CMR projects (Norgaard 1988; Martínez and Sain 1983; Doelman 1989; Anderson, Herdt, and Scobie 1986). The approach developed in the chapters that follow is valid for examining a wide-ranging CMR program. This study also differs from previous studies in that both research and extension costs are included in the cost of inducing changes in crop management.

The specific objectives of the study are to:

- Present a methodology for assessing the impact of information and technologies generated by a CMR program.
- Demonstrate the methodology by estimating the return to CMR conducted in the Yaqui Valley of Mexico between 1977 and 1987.
- Show how a program aimed at monitoring the impact of CMR on farmers' practices can be designed and implemented.

The remainder of this chapter discusses the process of technical change and its relation to CMR. Chapter 2 presents a framework and empirical methods that can be used to evaluate CMR. Chapter 3 describes the agricultural setting of the CMR program evaluated in Chapter 4. Chapter 5 discusses the implementation of a program for monitoring the impacts of CMR. The final chapter summarizes the main conclusions.[4]

Table 1.1. Estimates of percentage of crop research budgets spent on crop mangaement research

Author(s)	Country/ region	Crop	Estimated percentage of research resources to CMR
Cuevas-Pérez et al. (1989)	Central America	Rice	36 [a]
Polanco (1989)	Mexico	All crops	55 [a]
Byerlee and Heisey (1987)	Punjab, Pakistan	Wheat	50 [b]
Araji (1989)	Western USA	Wheat	78 [b]
This study	Northwest Mexico	Wheat	45 [b]

[a] Based on categorization of human resources.
[b] Based on categorization of experiments.

4 An abbreviated version of the main results of this study is published in Traxler and Byerlee (1992a).

Conceptual Issues

A stylized account of technical change

Changes in crop management practices must be considered within a broader context of technical change. Many developing country farmers operate in an environment dramatically different from the one that existed 25 years ago. The process of technical change in developing country areas that experienced the greatest improvements in productivity can be divided into three phases — an early and a late Green Revolution phase, and a post-Green Revolution phase.[5] This model of technical change fits certain irrigated areas of the Third World, such as the Punjab of India or the Yaqui Valley of northwestern Mexico. In these areas, average wheat yields now exceed 3 t/ha, average fertilizer applications are above 180 kg/ha, and most farmers use chemical pesticides.

The productivity increases that occur in each phase of technical change are driven by different forces. The driving force of the early phase of the Green Revolution was the spread of improved (or "modern") wheat and rice varieties. By 1971 modern varieties were grown on 70% of the wheat area in the Punjab of India, 53% of the area in the Punjab of Pakistan, and virtually 100% of the wheat area in Mexico's Yaqui Valley. The adoption of the new varieties and modest doses of nitrogenous fertilizer resulted in a 40% yield improvement; the additional production costs were relatively small.

In the late Green Revolution period — the so-called "intensification phase" — yield increases were driven by substantial increases in the level of agricultural inputs used by farmers, especially fertilizer. Rising input levels were accompanied by modest but steady improvements in the yield potential of the newer cultivars that were released. During the late Green Revolution phase, not only did nitrogen use increase several fold, but farmers also began investing in other inputs, especially phosphatic fertilizers and chemical pest control methods. Increased levels of inputs were justified by the improved varieties' greater responsiveness to inputs (see Figure 1.1 for an example).

Because they now use high levels of inputs, however, farmers are operating on the relatively flat portion of the response curve, so that the effect of future increases in input levels will be modest. For example, in the Punjabs of India and Pakistan, the marginal grain-to-nutrient ratio, which was around 15:1 when modern wheat varieties were introduced, may now be as low as 5:1 (Grewal and Rangi 1983, Aslam et al. 1989, Sarma and Ghandhi 1991).

In the post-Green Revolution phase of technical change, the management challenge faced by farmers is no longer the relatively simple task of seeking a new variety which by itself increases yields, nor is it a case of raising input levels. The challenge is to manage the complex interactions of several inputs.

5 See Byerlee (1992) for a more detailed elaboration of this model.

Several studies have suggested that to increase productivity in the post-Green Revolution phase farmers will need to rely on more efficient input use (CIMMYT 1989a, Byerlee 1987, Edmeades and Tollenaar 1988, Herdt and Mandac 1981:399) and hence will rely on the development and diffusion of improved crop management techniques. Both yield levels and farmers' input investment are now several times higher than they were in previous decades, so the potential returns to improvements that either protect those yields (such as pest control) or increase the input response efficiency are much higher than they were in the past.

Crop management research in the process of technical change

These three stages of productivity increase, driven by modern varieties, input intensification, and input efficiency, are consistent with Schultz's (1964) "high payoff" model of agriculture, which identifies three productive avenues of investment in the agricultural sector: 1) the scientific capacity to produce technical knowledge; 2) the industrial capacity to develop, produce, and supply new technical inputs; and 3) the capacity of farmers to use modern agricultural inputs effectively. Schultz emphasized that there were very strong positive interactions among the three investments. Failure to invest in either of the first two areas ensures stagnation in the agricultural sector because of the absence of the potential for technical change at the farm level, but farmers' capacity to take advantage of new technical opportunities is also crucial.

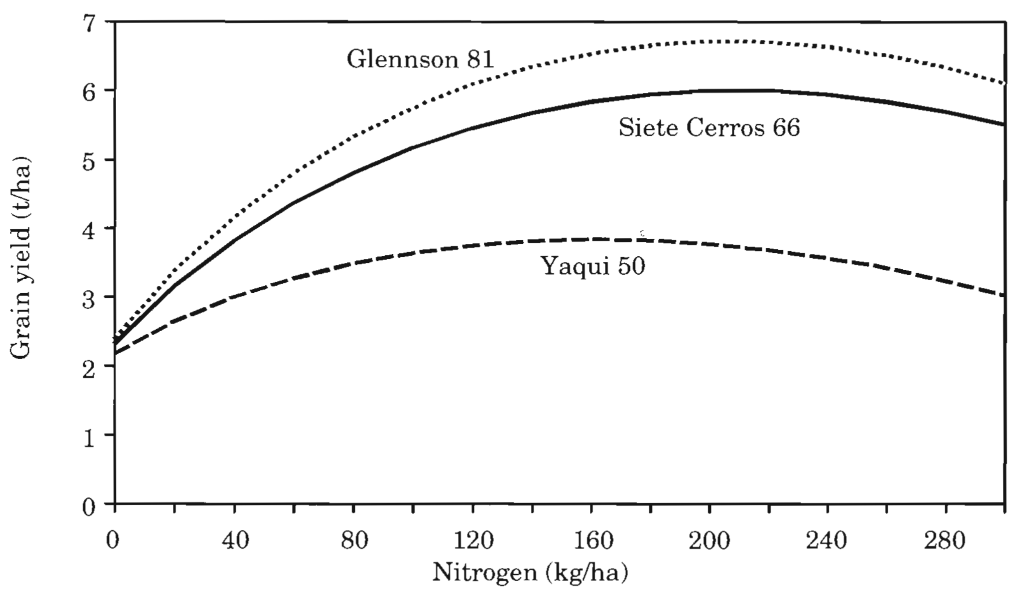

Figure 1.1 Nitrogen response for wheat varieties from different eras.
Source: Traxler and Byerlee (1992b).

Schultz noted that the introduction of improved technical inputs produces an efficiency "disequilibrium," during which farmers use an inappropriate mix of inputs. A period of adjustment to a new equilibrium is required for farmers to learn to use the new inputs effectively. This period of adjustment is composed of two different processes — the discovery of cultural practices suited to the new inputs and the learning of those practices by farmers. The second process has received considerable attention. It has been confirmed that education and extension shorten the time that farmers need to achieve the new efficiency equilibrium, and hence Schultz's hypothesis of high social returns accruing to investments in these areas holds (e.g., Huffman 1978, 1974, 1977; Jamison and Lau 1982). The first process — the discovery of more productive inputs and farming methods — has been closely examined only for improvements in plant varieties. The questions of where farmers receive information on new or more efficient crop management practices, and whether publicly sponsored research has any impact, have received only limited attention.

The importance of research aimed at generating improved crop management practices becomes clear when the "poor but efficient" hypothesis is considered. The hypothesis implies that, in a traditional production system, efficient methods of employing a limited number of inputs have evolved over a period of perhaps several generations. It can also be imagined that efficient methods of husbanding new inputs evolve as farmers learn by doing. But it is certainly reasonable to ask what might be the result of another approach, in which focused scientific enquiry identifies and investigates specific crop management problems and methods. The literature to date has not evaluated the impact of public sector research in inducing more efficient crop management practices among farmers.

Compared to changes in new technical inputs, changes in crop management practices are likely to involve an even greater interaction between research, education, and extension. Information, the primary product of CMR, is more difficult to transfer than physical inputs, and changes in management practices are often more complex to implement. There are also many potential alternative sources of information about crop management, including input suppliers, the information farmers derive from their own experimentation, information from other farmers, and the media (print, television, and radio). Is public investment in providing crop management information redundant? If public research provides little information on crop management in addition to what is available from other sources, the returns to public research will be low. It would follow then that CMR could be reduced with little effect on the rate of technical change in agriculture. The next chapter presents an analytical framework for examining these kinds of issues.

2

The Analytical Framework and the Empirical Model

Previous studies have provided estimates of the *potential* value of crop management information, especially information on optimum fertilizer rates,[6] but have not attempted to relate the efforts of agricultural scientists directly to farmers' implementation of improved crop management practices. The *realized* value of the information from CMR, of course, is zero until it is assimilated by farmers. Farmers are prevented from assimilating information from CMR for any number of reasons. For example, additional information on fertilizer use may simply not reach them; they may reject the research findings; or for some reason they may be unable to implement the recommendation. Thus in evaluating returns to CMR it is important to examine the extent to which farmers do, in fact, follow recommendations derived from experimentation.

This study was conducted from an *ex-post* perspective, so it evaluates the realized, rather than potential, benefits of CMR. This chapter presents first the economic framework and then the empirical procedures used in the study, which made it necessary to 1) examine the entire range of activities of a particular CMR program to identify all useful products developed by the program, 2) monitor farmers' acceptance of the research products, and 3) quantify both the costs and the social benefits of the research program.

The Analytical Framework

Both crop breeding and CMR seek to enable farmers to increase net farm income. Society benefits from research discoveries when fewer inputs are required per unit of output. The resulting increase in productivity is referred to as the "economic surplus." When evaluating research benefits, it is immaterial whether a cost reduction comes about through an increase in yields or a decrease in the cost of attaining a given yield.[7] In either case, the cost reduction induces farmers to increase aggregate production.

The total economic surplus generated by more efficient production methods can be represented by a shift in the output supply curve. Since CMR is relatively site-specific and each research station normally issues recommendations for specific production zones, it is generally valid to assume that the "small

6 For example, the potential value of more precise fertilizer information has been evaluated within such an *ex-ante* framework; see (among others) Anderson (1968, 1975), Anderson and Dillon (1968), Doll (1971, 1972), Drynan (1977), Perrin (1976), Ryan and Perrin (1974), Havlicek and Seagraves (1962), and Byerlee and Anderson (1969)

7 Note that it is possible for yield increases to occur without society being any better off if the cost of production increases by an amount equal to the value of the increase in output.

country" case applies. In the small country case, the market price of output is not affected by the supply increase. The total change in economic surplus, therefore, is an area resembling the shaded area in Figure 2.1. The small country assumption also implies that prices of inputs are unaffected by the increase in output (i.e., input supply is perfectly elastic). Given these conditions in the output and input markets, the change in surplus is exactly equal to the change in variable profit or gross margin (total revenue less variable costs) summed over all farmers (Just, Hueth, and Schmitz 1982).

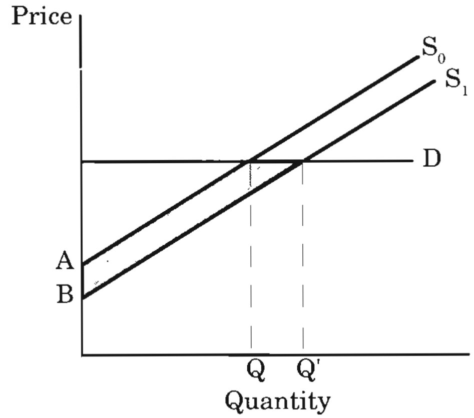

Figure 2.1. Gains in ecocomic surplus in a situation of pefectly elastic demand (research shifts the supply curve from S_0 to S_1).

Society's net benefit from the agricultural research effort, therefore, is the difference between the research-induced change in variable profit and the cost of the research. The most commonly used indicator of the efficiency of research investments is the internal rate of return (IRR). The IRR is the maximum interest rate that a project could pay on the resources invested and still break even (Gittinger 1982). Mathematically, the IRR is the discount rate, r, such that:

$$\sum_{t=1}^{T} (B_t - R_t - E_t) / (1 + r)^t = 0 \,, \qquad (2.1)$$

where:

B_t = economic surplus generated by CMR in year t;
R_t = research costs related to crop management in year t;
E_t = extension costs related to crop management in year t; and
r = the discount rate.

The remainder of this chapter will explain how the two components of this model (changes in variable profits, and research and extension costs) can be measured in an empirical study.

The Empirical Model

Crop management research has the potential to produce both new technological components (e.g., a new input) and new information. In practice, new technological components for improving crop management — new chemical inputs, improved machinery, and so forth — are developed mostly by the private sector. The public sector focuses most of its effort on providing information about these and other practices to improve productivity in a given situation. Hence the main product of CMR in the public sector is improved information.

It is more challenging to identify the production, diffusion, and impact of crop management information than of improved seeds because information is intangible. Since there are also many potential alternative sources of information on crop management, including input suppliers and farmers' own experimentation, care must be taken to separate the influence of research-generated information from the influence of these other sources of information.

Empirical issues which are trivial when the products of plant breeding programs are considered must receive careful treatment when the benefits of CMR are assessed. Three such issues are important for this study. The first issue is simply how to recognize the new research product. The products of CMR will range from something as obvious as a new rotation to something as subtle as a new finding concerning the relationship between seed depth and germination for a specific variety. Such findings are, at some point, usually embodied in production recommendations that are made available to farmers. The recommendations may be diffused directly to farmers through field days, through extension personnel, or through technical bulletins.

The second issue is how to identify whether or not the research product has been adopted by farmers. There is little doubt that a farmer planting a newly released wheat variety has benefitted from crop breeding research. Crop management research, on the other hand, can result either in the discovery of totally new practices, such as zero tillage, or in incremental changes to existing practices, such as an adjustment in the optimal dosage of nitrogen. The point at which the first type of innovation is adopted is relatively simple to identify; for the second type of innovation it is often difficult to measure adoption.

The third empirical issue that must receive attention is how to establish a *causal* link between the research effort and the adoption of a new or modified management practice. The planting of a newly released wheat variety can serve as both a necessary and sufficient condition for assuming an impact from plant breeding. It is not necessary to allow for the possibility that the farmer has developed the new variety on his/her own. When the research product is more precise information on pesticide use, however, it is conceivable that the information came to the farmer from sources outside of the research system or that he or she developed it independently of the public research effort.

The logical framework

The management of any crop can be reduced to a number of separate practices that determine the production outcome. Following the definition of CMR given in Chapter 1, it is reasonable to assume that a CMR program has the potential to produce multiple and varied research products related to the type of input under consideration, its dosage, and the timing and method of application. The impact of a CMR program can therefore be evaluated in five logical steps:

1) Identify the research areas for which an improved management practice has been embodied in a new recommendation (i.e., new information) issued to farmers.

2) Determine the practices that farmers have modified in a manner consistent with the new recommendation.

3) Determine whether the revised recommendation has been the cause of the change in farmers' practices.

4) Measure the impact of each research-induced change in crop management practice on economic surplus.

5) Sum the economic surplus across practices and compare the benefit stream to the costs of CMR and extension.

Within this framework, the first three steps present conditions which should hold in order to link a given research initiative to an increase in variable profit. A research initiative that fails to meet any of these conditions cannot logically be judged to have had an impact on economic surplus.

Research products

Research products can be identified by examining changes in crop management recommendations. If it is to be of any benefit, the crop management knowledge derived through research must become a recommendation that is released to either farmers or extension agents. In evaluating a CMR program, it will be important to review the evolution of extension recommendations.

The potential for new research exists in each area. The fact that some areas are ignored and that some recommended best management practices remain unchanged for long periods simply acknowledges the need to allocate limited research resources among competing areas. The advantage of this method of organizing the analysis is that it reduces the risk of overlooking a significant research finding.

However, there are two caveats to this approach to identifying research products, each of which also applies to previous studies of plant breeding research. First, only research leading to new practices is considered; no value is placed on basic research. This is not a particularly damaging shortcoming, as knowledge developed through basic research is ultimately embodied in either applied or adaptive research findings, albeit with some delay. The more problematic caveat is that maintenance research is implicitly assigned a value of zero. For example, trials conducted to monitor insect resistance to common insecticides are a component of any research program in integrated pest management (IPM). If the trials find that current chemicals remain effective, the recommendation remains unchanged. The research is assigned a zero value in an *ex-post* study, although clearly the *expected* value of such research over the long term is positive.[8] Both of these limitations of the methodology — the zero value placed on basic research and on maintenance research — tend to underestimate the value of the CMR program.

Changes in farmers' practices

Changes in farmers' practices are identified through statistical analysis of farm survey information. Crop management practices can be classified in two ways. Some practices, such as seeding density or nitrogen dose, take on continuous values. Others, such as planting method, take on a limited range of discrete values. Information on practices at two points in time is the minimum amount of information needed to assess changes in practices, although clearly more information (from more frequent surveys of agricultural practices) is helpful.

Information on practices employed at the end of the period under evaluation can be collected through a survey of farmers. When baseline information from an earlier survey of the same population of farmers is not available, farmers can be asked to recall practices used at an earlier date. Such retrospective questioning usually works well for uncovering changes in discrete practices but is less satisfactory for measuring changes in continuous practices, since farmers may not remember precise quantities, dates, or products. Although retrospective questioning is less than satisfactory for the full range of management practices, it may nonetheless be the only option. In most cases it will give a sense of whether or not research findings are an important source of crop management information.

Given data on farmers' practices at two or more time periods, various statistical methods can be used to test for changes in practices over time (Traxler 1990). However, tests for changes in the distribution of practices using sample observations are not completely satisfactory for some practices. Most practices are only weakly conditioned by stochastic events. For example, phosphorus dose and seeding rate are decisions that, once made, are unlikely to be changed because of weather. On the other hand, planting date and insecticide application are strongly conditioned by weather or other random environmental events. Thus the changes in practices that result from research cannot be distinguished easily from changes that result from variability in environmental conditions, so the examination of evidence on causality takes on increased importance.

8 The analogous situation for plant breeding research is to assign a zero value to research that leads to the release of a disease-resistant variety to replace a variety whose disease resistance has broken down. If there was no gain in yield potential, past studies implicitly assigned such research a zero value.

Causality

As with other aspects of an empirical investigation, appropriate methods to examine causal relationships can be determined only after considering both the structure of the problem and the data available. Where a well-defined problem and corresponding data exist, a formal model can be constructed and the hypothesized causal relationship can be tested statistically. Relatively simple statistical models are available for examining causality for both continuous and discrete variables. A causality test for continuous variables can be constructed by categorizing farmers according to the level of intensity of contact with the research message (e.g., frequency of extension contact or regular attendance at field demonstration days). Qualitative choice models (including the probit and tobit), which test the importance of contact variables for the adoption of agricultural innovations, have also been widely used to identify factors that affect the adoption of agricultural innovations (Feder, Just, and Zilberman 1985).

In some cases the lack of data on the intensity of farmer-extension contact may rule out the use of formal statistical models to assess causality. This may be especially true when retrospective questioning is used to collect information on adoption of innovations. In such cases the problem should be viewed as one in which evidence is accumulated and less formal criteria are used to construct a simple decision rule. For example, heuristic minimum conditions would include: 1) the recommended practice and producer practice should have changed in the same manner during the study period; 2) dissemination of research results must have preceded the change in farmers' practice; and 3) it seems "unlikely" that farmers could have developed the change in practice without the benefit of formal research.

Whether formal statistical models or less formal approaches are used, the time spent accumulating evidence to support or refute causality is well spent. The extent that farmers accept or ignore CMR results provides valuable feedback to researchers and research administrators.

Calculating changes in gross margin

Given the change in variable profit per unit of area, $\Delta\pi_{it}$, the annual total value of an improved practice is given by:

$$QR_{it} = A_t \, \Delta\pi_{it} \, (K_{it} - K_{it}'), \tag{2.2}$$

where QRit is the total gross margin generated by innovation i in year t, and A_t is the total harvested area in year t. The term K_{it} - K_{it}' represents the difference between the percentage adoption of the innovation in year t in the presence of the CMR program (K_{it}) and the percentage adoption that would have occurred without the CMR program (K_{it}').

Farm survey data can be used to estimate the values of $\Delta\pi_{it}$, K_{it}, and A_t. It can often be assumed that $\Delta\pi_i$ is not time dependent. However, the percentage of farmers adopting the innovation and total area vary over time. The calculation of $\Delta\pi_{it}$ will be discussed next, and then the procedures used to estimate $K_{it} - K_{it}'$ will be described.

Measuring gross margin — There are two options for calculating the per-hectare impact of a given innovation on economic surplus: partial budgeting or yield (response function) estimation.

Partial budgeting is a non-statistical method for comparing the costs and benefits of a particular technology.[9] Technical information from controlled experiments as well as from farm surveys can be used to estimate the impact of new technologies on net farm income (CIMMYT 1989b). Because problems can arise if technologies perform differently under farmers' and researchers' management (Davidson and Martin 1965), information from farmer-managed verification trials is preferred.

Response functions use regression techniques to estimate the relationship between output and inputs employed (Dillon 1977). The effect of a given innovation on net farm income is derived through the specification of a relationship, such as:

$$Y_k = f(X_k, Z_k, I_k, \beta) + \varepsilon_k, \qquad (2.3)$$

where:

Y_k = per-hectare output of producer K;
X_k = vector of variable input levels;
Z_k = vector of environmental factors;
I_k = vector of crop management practices;
β = vector of coefficients to be estimated; and
ε_k = random error term.

Equation 2.3 presents production as a function of conventional inputs, environmental factors (such as weather, education, extension), and specific innovations or management practices. If all variable inputs are included in the X_k vector, the impact of the adoption of innovation i on variable profit, at output price P and holding all other inputs unchanged, is given by the partial derivative of yield with respect to the innovation (equation 2.4).

$$\Delta\pi_i = (dY_k/dI_k)\,P \qquad (2.4)$$

9 See Ryan and Perrin (1974) for the use of partial budgeting for calculating the value of a new fertilizer recommendation and Hertford et al. (1977) for calculating the value of a change in rice varieties.

The response function approach has both advantages and disadvantages compared to partial budgeting. One advantage is that the regression model is capable of statistically isolating the individual effects of production factors and provides a confidence interval for the estimate. Suspected interactions among technologies and inputs can also be tested statistically. Furthermore, the data used to estimate the production relationships are taken from farmers themselves, rather than from controlled experiments. On the other hand, the response function approach is more time consuming to implement than partial budgeting and will not always provide meaningful statistical results. A large amount of data is required and measurement errors or multicollinearity among inputs may lead to ambiguous statistical results.

Both of these analytical techniques have been widely used by agricultural economists. The choice of technique is ultimately guided by the nature of the data that are available. Estimating a response function may be preferred to partial budgeting when the data are free from the problems described above; in other cases, especially when information from farmer-managed trials is available, partial budgets can provide reliable information.

Aggregate adoption — Even after a causal link between research and the adoption of an improved practice has been established, it is possible that extension services, farmers, or the private sector could have eventually developed the new information without CMR (Martínez and Sain 1983). The advantage of a CMR program is that the efficiency of formal experimental techniques allows new information to be developed more quickly than it might be developed by farmers or other suppliers. Hence the value of the CMR program is given by the difference between the two adoption curves in Figure 2.2. In some cases, it is unlikely that farmers or other suppliers would have developed the innovation in question during the time period under analysis, and hence $K_{it}' = 0$. Since the adoption path in the absence of the CMR program cannot be known with any certainty, it may be appropriate to calculate the total gross margin under a range of assumptions to test the sensitivity of the benefit stream to the assumptions regarding K_{it}'.

Innovations are generally modelled as following an S-shaped cumulative adoption curve through time (Feder, Just, and Zilberman 1985). This curve is composed of three stages (Figure 2.2). The rate of adoption grows slowly during the first few years, climbs steeply during the middle years, and finally attains a ceiling, remaining at this upper bound until the innovation becomes obsolete. Because an accurate accounting of the total surplus generated by an innovation includes the value of future benefit streams, the full path of the diffusion curve of each innovation must be estimated.

It is unlikely that cumulative adoption percentages will exist for each year in the life of each crop management innovation. As noted earlier, information on the adoption of discrete practices can be collected by retrospective questioning of a representative sample of farmers. By asking farmers two questions — what year did they begin farming, and what year did they begin using a particular innovation — the full diffusion path can be traced. For example, if a survey of 150 farmers conducted in 1989 finds that 100 began farming in 1983 or before and that 15 of them were using phosphatic fertilizer in 1983, the cumulative adoption for 1983 is simply 15%. For innovations that have not yet attained their ceiling diffusion level, retrospective information can be used to estimate the parameters of a logistic equation (2.5) to predict future diffusion.[10] When transformed (equation 2.6), the S-shaped diffusion path can be estimated by Ordinary Least Squares Regression.

$$S_t = C / (1+\exp(-a-bt)) \qquad (2.5)$$

$$\log ((S_t / (C - S_t)) = a + bt \qquad (2.6)$$

where:

S_t = percentage of farmers using the innovation in year t;
C = assumed ceiling level of adoption;
b = rate of adoption; and
a = constant term.

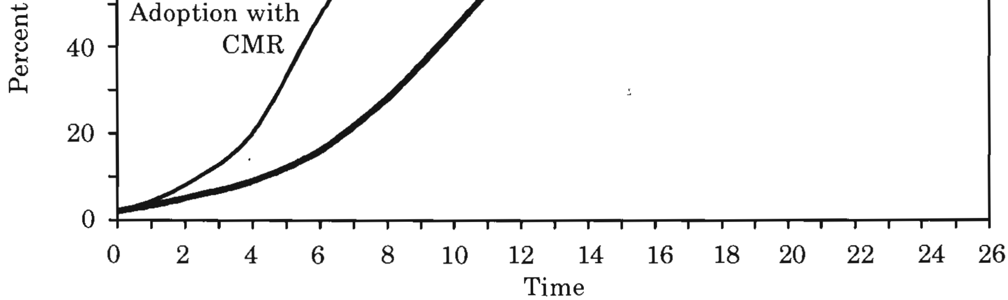

Figure 2.2. Logistic diffusion curve.

10 Griliches (1957) and Dixon (1980) discuss the estimation of cumulative diffusion curves more fully. Jarvis (1981) illustrates the use of an estimated logistic curve for projecting future adoption.

Costs of Technology Generation and Transfer

Measuring the cost of crop management research
Calculating the costs of CMR requires expenditure information that is unlikely to conform to normal accounting categories. This is particularly true if CMR on only a single crop is being examined. Research institutions are likely to report expenditures either by commodity or by discipline, but only rarely by crop and discipline.[11]

What other information might be used to supplement accounting data in making cost allocations? The best source of information is a description of the experiments that have been performed. Many experiment stations produce an annual summary of scientific activity, containing abstracts or at least titles of research projects funded during the year. Such information can be used to identify experiments pertaining to the management of the crop of interest and then to determine crop management expenditures by discipline and commodity. For example, if the entomology program budget is known and it is further known that, of the 10 research projects undertaken by the program, six pertained to insect control in maize and four to wheat, the program's expenditures would then be allocated by commodity on a 60-40 basis. Similarly, a wheat program reporting five varietal improvement projects, three on weed control and two concerned with plant spacing, thus allocates its resources on a 50-50 basis between wheat plant breeding research and wheat CMR. Overhead costs could be allocated to CMR either on the basis of its share of total experiments or its share of the total operating budget.

Cost of technology transfer
It is generally recognized that research and extension are highly complementary activities. This is especially the case for CMR in a post-Green Revolution setting, where provision of extension advice is an even more complementary activity for the adoption and successful use of improved crop management techniques than it is for germplasm. Given this strong link between research and extension, it would be misleading to present an estimate of the returns to research without accounting for the intensity of extension assistance. It is more appropriate to calculate a combined estimate of the return to the full technology generation and transfer effort. In most cases, total extension expenditures can be readily estimated, although, as with the case of research, these expenditures must be disaggregated by crop and then by discipline.

11 For example, an accounting category might exist which records annual expenditures by an entomology program. It is also possible that expenditures for wheat research are registered. One would not expect to find an accounting category that includes only research expenditures for "wheat entomology."

3

The Yaqui Valley

The Setting for the Study

The setting for the empirical part of this study is the Yaqui Valley, 1,800 km northwest of Mexico City on the arid coastal plain of the state of Sonora. The Yaqui Valley is a relatively homogeneous agricultural area spanning 220,000 ha of irrigated farmland. Heavy public investment has provided the valley with an excellent irrigation and road network. Farmers are also well served by suppliers of seeds, chemicals, credit, and machinery and labor services, so that Yaqui Valley agriculture more closely resembles the irrigated areas of nearby Arizona or California in the USA than the more traditional agricultural areas of Mexico.

Wheat, the most important crop in the valley, is planted on an average of 120,000 ha each year and accounts for some 40% of the total value of agricultural production in the Yaqui Valley. The valley supplies slightly more than 10% of all wheat consumed nationally. Cotton, sorghum, maize, safflower, and soybeans are the other important crops in the valley. Wheat is generally grown in a wheat-soybean, wheat-maize-cotton, or continuous wheat rotation.

Wheat production in the Yaqui Valley is a mechanized, high-input activity. The variable cost of production is nearly US$ 500/ha, requiring a 3 t/ha harvest to break even. Farmers provide only a small part of their own manual labor since unskilled farm labor is readily available and relatively cheap. Even farmers with small landholdings hire nearly all of the labor needed for irrigation, hand weeding, and operating machinery.

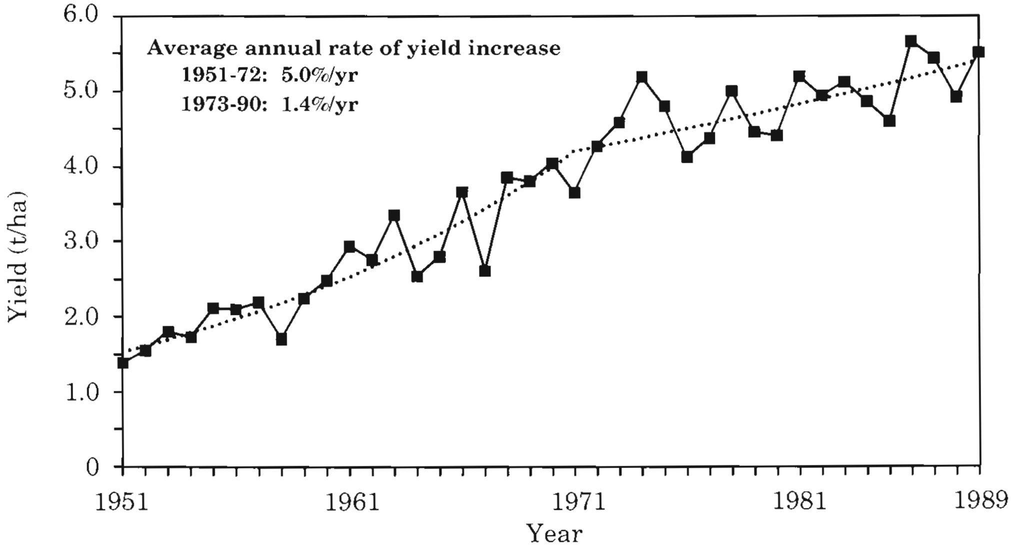

Figure 3.1. Average wheat yields and fitted trend, Yaqui Valley, Mexico.

At 5,100 kg/ha, average wheat yields in the Yaqui Valley are among the highest in the world. The increases that have occurred in land productivity over the past 40 years are impressive (Figure 3.1). Up to 1972 yields rose at an annual rate of 5% per year.

Since the early decades of this century, two forms of land tenure have existed in Mexico – the *ejido* system, which is composed of both individual and collective *ejidos*; and private land tenure. Land expropriated from large landholders was redistributed to rural communities to establish the *ejido* holdings. The government has retained the title to these lands, but has granted persons (*ejidatarios*) the right to farm the parcels and to pass this right on to heirs.[12] Although officially prohibited, the renting of *ejido* parcels is common.

The three classes of farmers in the Yaqui Valley (farmers with individual *ejido* parcels, farmers who have rights within collective *ejidos*, and private landowners) differ by the size of their holdings, sources of credit, education, and access to machinery services and technical assistance. Collective *ejidos* cover 100-600 ha, with an average holding of 5 ha per member. The individual *ejidos* range in size from 10 to 50 ha, while private farmers may operate holdings ranging from 20 to 300 ha. The individual *ejidatarios* face several disadvantages, including their reliance on hired equipment to perform field operations and on the less efficient public institutions for production credit. Private landowners and collective *ejidos* have much greater access to capital and usually own their own tractors, combines, and field equipment.

Farmers' levels of formal schooling also vary considerably. Thirty-five percent of the Yaqui Valley farmers interviewed had less than three years of formal education; at the other extreme, nearly 20% of the farmers had graduated from university. Private land owners tended to have more years of schooling than *ejidatarios*.

Research and Extension in the Yaqui Valley

Farmers in the Yaqui Valley are served by a well-developed research and extension system. Approximately 40% of researchers at the Campo Experimental del Valle de Yaqui (Yaqui Valley Experiment Station, CEVY) hold master's degrees and 25% hold doctoral degrees. This percentage of scientists with advanced training is higher than in most developing countries (Pardey, Roseboom, and Anderson 1991). The Yaqui Valley is also CIMMYT's main wheat breeding location, where scientists from CIMMYT's predecessor organization developed the short-statured varieties whose release in Mexico catalyzed the Green Revolution.

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12 Recent reforms in the law governing *ejidos* are expected to change this situation in the future.

Wheat breeding is the main focus of CEVY wheat research. Close collaboration between CIMMYT and CEVY wheat breeders results in a steady stream of new varieties for release, so that in most years farmers are able to choose from 10 or more viable commercial varieties. The yield potential of the commercial bread wheat varieties has increased at a rate of about 1% per year (Ortíz-Monasterio et al. 1990, Waddington et al. 1986).

Researchers at CEVY conduct a program of CMR, with a limited amount of on-farm research. A number of CEVY scientists, however, have established very good contact with farmers and several of the scientists are themselves part-time farmers.

The communication of research results to farmers is good because of a dense extension support network: 200-300 field extension agents cover the valley's 220,000 ha. The Secretaría de Agricultura y Recursos Hidráulicos (the Ministry of Agriculture and Water Resources), the Ejido Union, and the agricultural credit bank are the main public extension sources, while credit unions and private consultants offer private services on a per-hectare fee basis. During the 1989 wheat season, 80% of the farmers surveyed received at least one extension contact per month, and 65% had one or more contacts per week. The collective *ejidos* had more contacts than either the individual *ejidatarios* or the private landholders.

Survey Information on Farming Practices

The sample

Information on wheat cultivation practices comes from a series of farm surveys conducted in 1981, 1982, 1987, and 1989 by the CIMMYT Economics Program in collaboration with CEVY. A two-stage sampling procedure was used to select 100 farmers for the initial survey in 1989 (Byerlee and Flores 1981). In the first stage, irrigation blocks were randomly selected. In the second stage, the first farmers (up to a maximum of five) to be located within the selected blocks were interviewed.

In 1982 only farmers from the 1981 sample who practiced a wheat-wheat or wheat-soybean-wheat rotation were interviewed, which reduced the sample size to 74 cases.[13] For the 1987 survey, a sub-sample of 41 of the farmers interviewed in 1981 was randomly selected. In 1989, an effort was made to contact all of the farmers who had been surveyed in 1981. To maintain a sample size of approximately 100, farmers who did not plant wheat were replaced with farmers growing wheat on adjoining parcels or with farmers from three additional randomly selected irrigation blocks.

13 Several completed questionnaires were eliminated from both the 1981 and 1982 surveys after it was judged that the farmers had given unreliable information when interviewed. They were *ejidatarios* who had made up answers to the survey questions rather than admitting that they were renting out their parcels.

The basic unit of analysis is the individual field, which ranges in size from 3 to 60 ha. All information was collected by direct questioning and by observations of fields. The surveys conducted prior to 1989 did not contain detailed information on education, extension contact, or sources of technical information. Information on these variables was collected during the 1989 survey.

Agricultural practices

Wheat production in the Yaqui Valley has entered a "post-Green Revolution" phase. Chemical fertilizers and semidwarf wheat varieties have been used since the early 1960s and chemical pesticides for nearly two decades. Therefore research issues related to the diffusion of improved inputs are no longer important. Inputs are used at high levels, and farmers' dominant concern is to protect crops from insects and weeds. This section refers to the survey data (summarized in Table 3.1) in reviewing the input levels and other practices used in wheat production.

New wheat varieties rapidly replace older ones in the Yaqui Valley. For most varieties, the time from initial release to adoption and then to commercial disappearance may be six years or less. A notable change since 1982 is the increased importance of durum wheat varieties.

The rotation information contained in Table 3.1 suggests that farmers are reasonably responsive to output prices in their choice of rotation. For example cotton, presently the crop competing most strongly with wheat, was planted by just 2% of farmers in 1987 but by 22% in 1989. The area planted to soybeans, the only spring-summer crop that can be planted in rotation with wheat, is largely determined by water availability. Fewer farmers planted soybeans in 1989 than in other years because water supplies in the valley were low.

Two important changes in land preparation have occurred since 1981. The first, the adoption of a new planting method, is discussed in Chapter 4. The other change has been the increase in the number of farmers using pre-planting irrigation for weed control. This is not a new technique, having appeared in extension bulletins as long ago as the late 1950s, but it was used by just 40% of farmers in the early survey years compared to over 80% in the later years. Why this innovation spread so rapidly in the mid-1980s is not clear. It may relate to the more flexible irrigation scheduling now permitted by irrigation authorities, increased emphasis by extension agents, or improved availability of farm equipment in the valley. Apart from the adoption of these two techniques, land preparation has changed little. The proportion of farmers subsoiling and plowing and the average number of harrowings were unchanged over the survey years.

The surveys failed to uncover any significant change in weed incidence or in the use of herbicides. Grassy weeds were a problem in about 15% of the fields, although few farmers used herbicides for grassy weeds. The apparent increase in hand weeding over time may result from the use of post-harvest follow-up surveys in 1987 and 1989, but not in 1981 or 1982. The earlier surveys may have missed the late season weeding, which is a common practice in the valley. However, the adoption of the ridge planting system (see Chapter 4) has clearly encouraged more hand weeding.

Fertilizer doses have increased significantly. The average level of nutrients applied to wheat has risen by 33% since 1981 to reach 270 kg nutrients/ha in 1989. The proportion of farmers applying phosphorus has increased by approximately 20%, so that most farmers now apply phosphorus.

Table 3.1. Summary of farmers' production practices for wheat in the Yaqui Valley, 1981-89

	Survey year			
	1981	**1982**	**1987**	**1989**
Number of fields surveyed	91	74	41	101
Previous crop, spring-summer (%)				
Fallow	72	39	20	81
Soybean	28	61	81	19
Previous crop, fall-winter (%)				
Wheat	59	100[a]	91	66
Sorghum-maize	1	0	5	8
Cotton	19	0	2	22
Sesame	12	0	0	2
Safflower	9	0	2	0
Watermelon	0	0	0	2
Wheat type (%)				
Durum wheat	19	18	46	44
Bread wheat	81	82	54	56
Varieties planted (%)				
Mexicali[b]	19	..	..	..
Nacozari	53	..	..	..
Yavaros[b]	..	19	..	..
CIANO	..	53	..	..
Altar[b]	..	..	42	41
Tonichi	..	..	12	..
Opata	..	..	..	31
Others	28	28	46	28

[a] Sample selected to include only fields in wheat rotation.
[b] Durum wheat varieties.
na = not available.

continued...

Table 3.1. (continued)

	Survey year			
	1981	1982	1987	1989
Land preparation				
Subsoil (%)	35	na	27	25
Plow (%)	52	na	51	65
Disk harrow (avg. number)	3.0	na	2.7	2.8
Total no. operations	6.8	na	6.1	7.1
Planting date (median)	5 Dec.	9 Dec.	10 Dec.	6 Dec.
Planting method (%)				
Broadcast	4	0	5	10
Row planter	96	100	95	90
Seeding rate (kg/ha)				
Average	156	151	156	158
Ridge planted	76	75	122	125
Other methods	163	156	175	175
Pre-planting irrigation (%)	40	40	83	82
Fertilizer				
Nitrogen (kg/ha)	176	194	218	230
Phosphorus (kg/ha)	30	14	40	37
Total (kg/ha)	202	206	259	269
Number of nitrogen applications	1.2	1.4	1.7	1.7
Percent using gas (NH_3)	19	26	44	52
Percent using granular urea	46	51	71	69
Percent using phosphorus	59	55	83	76
Insecticide use (%)	82	64	27	56
Herbicide use (%)				
None	41	47	56	54
Broadleaf	40	30	42	33
Grassy weed	6	11	0	8
Both	13	12	2	5
Hand weeding (%)[c]	34	45	54	66

[c] The number of farmers hand weeding may be understated in the 1981 and 1982 surveys since survey data were taken before harvest.

continued...

Table 3.1. (continued)

	Survey year			
	1981	1982	1987	1989
Broadleaf weed score (%)[d]				
None or few	92	96	91	94
Some to serious	8	4	7	6
Grassy weed score (%)[d]				
None or few	84	83	70	81
Some to serious	11	17	29	19
Lodging (avg. % of fields)[d]	26	na	na	20
Plant stand (%)[d]				
Good	68	na	70	81
Average	27	na	30	18
Poor	5	na	0	1
Irrigation system (%)				
Ridges	6	6	37	33
Border strip	36	48	17	24
Contour	24	17	17	12
Furrows	34	30	29	32
Average number of irrigations	3.9	4.7	5.5	4.8
Yield (kg/ha)	4,748	na	6,105	5,163
Soil type (%)				
Clay	59	62	56	60
Alluvial	41	38	44	40
Soil salinity problem (%)	31	na	20	8
Tenancy (% of producers)				
Collective *ejido*	21	18	22	21
Individual *ejido*	33	37	32	39
Private property	39	42	46	38
Rented	8	4	0	3
Percentage who grow wheat for commercial seed production	11	5	5	10
Percentage who use rented tractor	31	36	24	24

[d] Based on field observation.
na = not available.

4

Crop Management Research in the Yaqui Valley

The framework presented in Chapter 2 proposes that the evaluation of the benefits from CMR be conducted in five steps: 1) identifying the research products, 2) identifying the changes in farmers' practices, 3) appraising the evidence of causality between research and changes in farmers' practices, 4) estimating the impact on net farm income of the changes in practices, and 5) comparing the benefit stream to the costs of CMR and extension. The first section of this chapter applies steps 1-4 to wheat CMR in the Yaqui Valley. This is followed by a discussion of the costs of the CMR and extension effort, and an estimation of the internal rate of return to research over the reference period 1977-88 (step 5), for which data on research costs and changes in farmers' practices are available.

The Research Impact

Step 1: Identifying the research products
Production guides are published by CEVY for each crop grown in the valley. The guide for each major crop is updated annually based upon research results. The wheat production guide[14] runs to approximately 25 pages, and some 1,000-5,000 copies are distributed annually. Ten or more researchers, representing various disciplines — plant breeding, production systems, fertility, soil science, irrigation, weed science, entomology, and pathology — coauthor the guides. Crop management recommendations are discussed in 10 sections of the guide: land preparation, planting date, seeding rate, planting method, phosphorus, nitrogen, weed control, insect control, irrigation, and harvest technologies.

Recommendations for six of the 10 practice areas either remained completely unchanged over the period for which the guide was reviewed (1976 to 1988), or they incorporated only minor changes unlikely to be important to farmers. The recommended harvest and irrigation practices remained unchanged. The only change in the recommended land preparation practice has been that, since 1981, it has been suggested that deep subsoiling be performed once every three years. This change is not an important one since subsoiling was not a new practice, even in 1981 (Byerlee and Flores 1981). Another change is that the suggested optimal planting date has been moved from 1 December to 10 December.

Nitrogen response and chemical weed control are two relatively active research areas, but neither has resulted in notable changes in recommendations. Nitrogen recommendations are published in a table that lists recommended

14 *Guia para producir trigo en el sur de Sonora* (issues published from 1977 through 1989, various authors).

nitrogen dosages according to rotation, soil type, and varietal maturity class.[15] Some of the cells for nitrogen recommendations change nearly every year, as some recommended dosages are increased and others are reduced, but the changes have tended to cancel each other out. The net result has been that the average recommendation has remained nearly unchanged over the study period. There has also been some change in the herbicides recommended as new products have become available, but otherwise the weed control recommendations have not changed.

A significant new technology that began appearing in the production guide in 1980 is the method of planting in ridges (*surcos*). This new planting method uses both a different plant arrangement and a different system of irrigation than the traditional methods. A row planter, rather than a small grain seed drill or broadcaster, is used to plant one, two, or three rows of wheat on top of raised ridges which are 70-80 cm wide. The recommended seed rate for this new planting method is significantly lower than for the traditional methods. The ridges are separated by shallow furrows used for distributing irrigation water and which obviate the need to raise borders for irrigation.

The recommended approach to the use of phosphorus has changed over the study period. Prior to 1980, specific recommendations were published in a table similar to that used for nitrogen, in which the dosage was conditional on rotation, soil type, and variety. Since 1980 it has been recommended that all fields be tested for available phosphorus.

The recommended insect control strategy has also changed significantly, evolving into an integrated pest management (IPM) approach. Before 1987, the guide simply listed which chemicals should be applied to combat each insect species. In the production guides published after 1987, control strategies for each pest are discussed in more detail. Specific recommendations for monitoring both pest and predator populations are explained, including the population levels at which chemical control is warranted. For certain insects, it has been recommended since 1987 that an extra irrigation is a more effective form of control than using chemicals. The recommendations emphasize that chemical control should be employed only when absolutely necessary because of the adverse effects on predator populations.

This review of crop management recommendations issued by CEVY since 1977 reveals significant changes in three practices — planting method, phosphorus use, and insect control. Minor changes occurred in three practices — land preparation, nitrogen use, and planting date. The next step in evaluating the benefits of CMR is to assess the extent to which farmers have taken up these six practices.

15 In other words, the nitrogen recommendation table contains 3 (rotations) x 2 (soil types) x 3 (maturity classes) = 18 cells.

Step 2: Which practices have farmers changed?
Data from the 1981, 1982, 1987, and 1989 surveys are used to examine changes in farmers' practices. Of the six practices for which the recommendation has been modified, nitrogen dose and planting date take on continuous values, whereas subsoiling, planting method, phosphorus, and use of insecticides are analyzed by looking for changes in the proportion of farmers using the recommended practice. The statistical technique used to test whether or not farmers have changed their level of input use over time is the Friedman rank test, which has the null hypothesis that the distribution, $F_i(x)$, of the level of input use is the same in all survey years. That is:

H_o: $F_1(x) = F_2(x) = F_3(x) = F_4(x)$, and

H_A: at least one sample tends to have higher observed values.

For discrete practices, a statistical test for a change over time in relative frequency of the outcome of interest is used which relies on the Chi-squared distribution:

H_o: $\Theta_1 = \Theta_2 = \Theta_3 = \Theta_4$ (proportions the same in all samples), and

H_A: proportions not the same.

Land preparation — The new recommendation that was issued concerning land preparation was that subsoiling be performed at regular intervals in clay soils. The proportion of farmers who employ this practice has not changed significantly over the period of interest (Table 4.1).

Nitrogen use — A large increase in the use of nitrogen occurred between 1981 and 1989. The mean level of nitrogen application rose in each survey, resulting in a total increase of some 30% between 1981 and 1989.

Planting date — There was no statistically significant change in planting date. The median planting dates for the four surveys are 5, 4, 10, and 6 December. The average planting date has been between 5 and 12 December in all survey years, and in three of the four years has been between 5 and 9 December. This range of dates is small and falls within the range of optimal dates given by CEVY.

Phosphorus — The mean level of phosphorus application has risen over time, but this trend is the result of more farmers applying phosphorus rather than of a change in the dosage applied. The average phosphorus dosage applied by farmers has varied by only 2 kg/ha, but the share of sample farmers applying fertilizer increased from 59% in 1981 to 78% of sample farmers in 1989. The Chi-squared test shows that the change in proportion of farmers using phosphorus is significant.

Planting method and seeding rate — Farmers' use of ridge planting increased significantly between 1981 and 1989. In 1981 just 8% of farmers planted on ridges, whereas in 1987 and 1989 more than 30% employed this practice. An analysis of seed rates by planting method reveals that farmers have accepted the CEVY recommendation to use less seed when planting on ridges. However, farmers' seed rates for this practice are still much higher than the recommended rate of 50-60 kg/ha. Although farmers who plant on ridges have increased their seed rate over time, this rate is still much lower than that used by other farmers. The seed rate used in ridge planting has risen over time primarily because in 1981 and 1982 all but one of the ridge-planting farmers were commercial seed producers. Commercial seed producers use less seed than farmers who produce grain, since seed producers seek to increase the yield per unit of foundation or breeder seed. In later years, more commercial grain farmers adopted ridge planting.

Table 4.1. Summary of changes in crop management practices, 1981-89

Practice	1981	1982	1987	1989	Test statistic[a]	Degrees of freedom
Land preparation (%)						
Subsoil clay soils	32	na	36	23	1.8 [b]	2
Planting method (%)						
Use ridge method	8	5	37	33	44.6 ***[b]	9
Seeding rate (kg/ha)						
Ridge method	76	75	122	125	14.3 ***[c]	287
Traditional method	163	156	175	175		
Planting date						
Median date	5 Dec.	9 Dec.	10 Dec.	6 Dec.	1.1 [d]	3
Fertilizer use						
Nitrogen (kg/ha)	176	194	218	230	30.7 ***[d]	3
Phosphorus (% apply)	59	56	83	78	16.9 ***[b]	3
Insect control (%)						
Apply insecticide	82	64	27	56	39.1 ***[b]	3

[a] Significance at the 1% level of probability denoted by ***.
[b] Chi-squared test.
[c] t-test of difference in seed rate by planting method.
[d] Friedman rank test.

Insecticide use — Farmers used far less chemical insecticide in the last two survey years than in the first two. Seventy-four percent of the farmers surveyed before the insect control recommendation was changed in 1987 used chemical insect control, compared with an average of 48% of those surveyed in 1987 and 1989.

Step 3: Evidence of causality between recommendations and practices
The first two steps identified six practice areas in which recommendations were modified. Of these, farmers made changes in only four practice areas — nitrogen and phosphorus use, planting method, and insecticide use. Now evidence of causality between the research findings and the changes observed in farmers' practices will be examined.

Nitrogen and phosphorus use — Compelling evidence exists that changes in the use of nitrogen and phosphorus were unrelated to research findings and subsequent changes in the recommendations made to farmers. The principal modification in the phosphorus recommendation was that soil testing should precede application. This recommendation was followed by just 13% of farmers in 1989 (Table 4.2).

Table 4.2. Distribution of year in which soil test was last performed

Year	Percent	Cumulative percentage
1989	13	13
1988	11	25
1987	14	39
1986	8	47
1985	3	50
1984	4	54
1983	2	56
1982	4	60
Prior to 1978	40	100

The evidence that farmers do not follow nitrogen recommendations is even more convincing. In Figure 4.1 nitrogen levels reported by each sample farmer are plotted against the recommended level, given the rotation, soil type, and variety sown in each field in the 1981 and 1989 seasons. Points along the 45° line in each figure represent farmers who apply exactly the recommended amount of nitrogen. Points below the line represent farmers who apply less than the recommended dose, while those above the line apply more than the recommendation. The scatter of observations shows no linear relationship between the recommended and applied level in either figure.[16] It is also clear that

16 This is confirmed by the Pearson correlation coefficients between nitrogen recommendation and nitrogen application for the four surveys of .07, -.02, -.12, and -.03.

over time farmers are moving away from the recommended nitrogen dose. In 1981, 15 farmers used the recommended dose or less. In 1989 only one farmer was in this category. The average dose of nitrogen recommended for sample

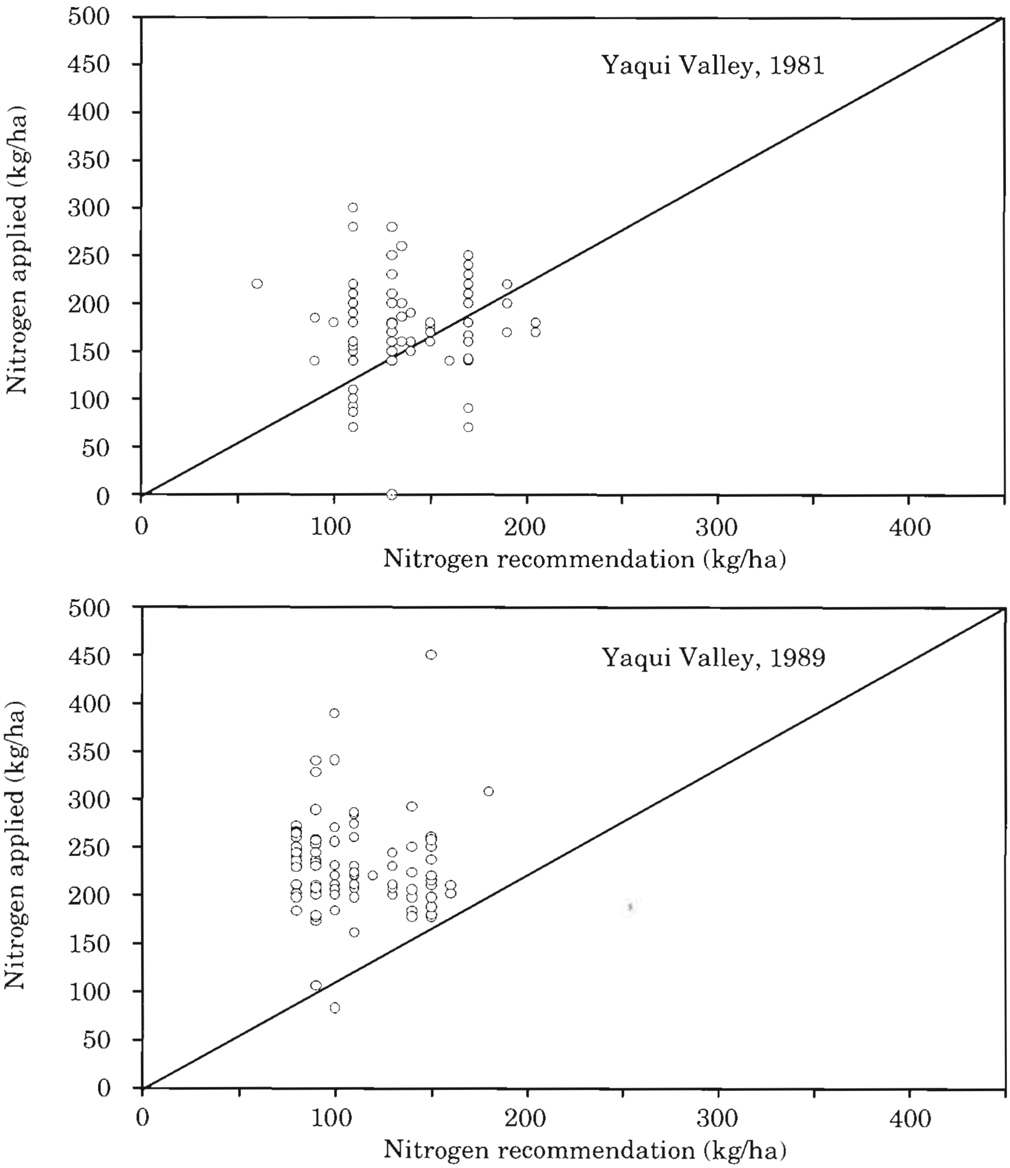

Figure 4.1. Relationship between average recommended nitrogen levels and average levels applied, Yaqui Valley, Mexico, 1981 and 1989.

fields (given soil type, planting date, and rotation in each field) in 1989 was 136 kg/ha, while farmers applied an average of 230 kg/ha.

Planting method — Research findings were judged to have been a critical element in farmers' adoption of the new planting method. Ridge planting was first used in the Yaqui Valley in 1980, after research by CEVY in the mid-1970s to develop this planting technique (Moreno 1989). A substantial effort was also made by CEVY to extend the new practice to farmers through demonstrations and field days. This is also the type of innovative practice that farmers would be unlikely to experiment with and perfect on their own.

Insecticide use — Integrated pest management (IPM) is also the kind of practice that would be unlikely to evolve without considerable research input. The theoretical foundation for believing that information can substitute for the use of chemical inputs in insect control is well established (e.g., Feder 1979, Taylor 1980). Through IPM programs, information on the dynamics of pest and predator populations, the effectiveness of insecticides, and alternate pest control methods reduces the demand for prophylactic applications of pesticides. Several empirical studies have found an inverse relationship between pest management information to reduce the subjective risk from pest losses and pesticide demand (Miranowski 1980, Pingali and Carlson 1985).

Research and extension efforts to establish IPM in the Yaqui Valley began in 1983 at CEVY. Research was initially directed at estimating several key parameters of the insect control problem in wheat — principally the control of aphids. Experiments focused on learning about the dynamics of pest populations, the kill function for commercially available insecticides, and the relationship between the level of infestation and the reduction in yield (J.L. Martínez Carrillo, CEVY entomologist, pers. comm.). Beginning in 1985, meetings were held to diffuse research findings to the extension agents who do most of the pest scouting in the Valley. During the growing season, radio and newspaper media give weekly estimates of pest and predator populations.

To see if there was evidence of a direct link between the CEVY research program and reduced insecticide use, farmers were asked a series of subjective questions on insect control as part of the 1989 survey. The results support the hypothesis that farmers have adopted the key aspects of the IPM program. Eighty-two percent of farmers stated that they were less disposed to use chemical control in 1989 than they were in 1984; 89% were willing to apply insecticide only after natural control by predator insects had been given a chance to take effect; and only 3% said that they used pesticides to prevent future pest attacks. Seventy-five percent stated that they apply insecticides only after consulting with extension personnel.

A probit model was fitted to obtain further evidence of the influence of research and extension contact on the decision to apply insecticide (Table 4.3). In this simple model, insecticide use in 1989 is posited to be a function of dichotomous variables for research and extension contact, producer characteristics, and weather.

Table 4.3. Results of probit estimation for the decision to use insecticide

Variable name[a]	Estimated coefficient	t-ratio
TECH	-0.373	-0.896
SIZE	0.390	2.584 **
DATE	-0.052	-3.880 **
PAMPHLET	-0.165	-0.495
UNIV	0.953	1.908 *
EXT	-0.231	-0.617
Constant	0.983	1.050

Note: Likelihood ratio = 38.13, 6 D.F.: equation significant at .01 level. Maddala R-square 0.35.

[a] TECH = dummy variable for consulting with an extension agent before applying insecticide (consulting with agent = 1, others = 0); SIZE = farm size (log of the size of the total land under cultivation); DATE = planting date; PAMPHLET = dummy variable for having received any research circulars (producers reporting having received circulars = 1, others = 0); UNIV = dummy variable for university education (university graduates = 1, others = 0); EXT = dummy variable for frequent extension contacts (weekly extension contact = 1, others = 0).

All variables have plausible signs. In 1989 farmers who planted later were more likely to spray. Frequent extension contact and familiarity with published research information reduces the probability of using insecticides (although the coefficient is not statistically significant). Farmers who consult with extension personnel are also less likely to resort to chemical insect control. Farmers having more land have less time (per hectare) to invest in scouting activities and rely more on insecticides. The positive sign of UNIV might be explained by the fact that pest scouting is time consuming. Since the opportunity cost of this time is higher for university graduates, they appear to prefer to substitute chemical control for increased time spent scouting. This statistical test of causality does not offer incontestable proof of a causal link between research and the reduction in pesticide use, but we do feel that, based upon the available evidence, the IPM research program has resulted in a significant decrease in insecticide use.

Nonetheless other factors may be related to reduced insecticide use. First, there may be large fluctuations in insect populations across survey years due to variation in climatic conditions.[17] Unfortunately, no

17 The CEVY entomologists suggest that the 1989 insect population was such that if farmers were using the same criteria as in previous years we would have observed an application rate of close to 100% (J. L. Martínez Carrillo, pers. comm.).

objective indicator of relative levels of insect populations in the Yaqui Valley across survey years exists to test this possibility. Second, the cost of insecticide use has risen somewhat over time,[18] suggesting that part of the decrease is a simple movement down the demand curve rather than a research-induced shift in the demand curve.

Step 4: Calculating changes in variable profit

Change in planting method — For only two practices, planting on ridges and IPM, is there reasonable evidence of impacts of CMR in farmers' fields. The next step is to determine the economic benefits resulting from the adoption of these practices.

The ridge planting method was presented to farmers as a cost-reducing rather than a yield-increasing technique. Ridge planting has the potential to reduce costs in several ways: the furrows allow a mechanical cultivator to be used to control weeds between the ridges; the furrows make hand weeding more efficient; and the seed rate can be reduced by 50 kg/ha or more (Moreno, Salazar Gomez, and Mendoza 1980).

Both of the approaches suggested in Chapter 2 for estimating changes in variable profit (the production function and partial budgeting) were applied to the case of ridge planting, and the results from the two methods were compared.

A modified form of the Cobb-Douglas production function was fitted to the pooled data from the 1987 and 1989 surveys:[19]

$$Y = A \prod_{i=1}^{n} X_i^{\alpha i} \, e^{\sum_{j-1}^{s} \beta_j Z_j} \qquad (4.1)$$

where Y is yield, the X_i are continuous variables, Z_j are dichotomous variables, and the α_i, β_j, and A are estimated parameters. Five classes of variable influencing yield were included: physical inputs, differences in varietal yield potential, weather effects, management, and agronomic practices. All variables are defined in Table 4.4.

The statistical results are satisfactory by most criteria. The model has a reasonable amount of explanatory power (considering that cross-sectional data were used), the majority of estimated coefficients are significantly different from zero, and, except for weed control expenditures, all parameters have the expected signs. The magnitudes of most coefficients also seem reasonable.

18 The cost of a 1 l/ha aerial application of the most common insecticide (Parathion Metilico) rose from 75 kg of wheat in 1981 to 111 kg of wheat in 1989.

19 The survey data from 1981 and 1982 did not contain yield information.

Climatic and varietal effects are important in explaining the variance of yield. The yield difference between bread wheat and durum wheat varieties was large in 1987 but negligible in 1989. Planting date also had a significant negative effect on yield.

The coefficient of nitrogen is not statistically different from zero. This is possibly due to the fact that nitrogen is applied in three forms (granulated, injected gas, and gas bubbled through irrigation water) and at various stages of production (from pre-planting through to the second irrigation). The yield response to phosphorus agrees closely with experimental results,[20] implying a

Table 4.4. Fitted yield function results

YIELD = 7.45 - .084 DATE - .024 DURUM89 + .138 BREAD87
(2.83)*** (0.71) (2.47)***

+ .239 DURUM87 + .086 PHOSPHORUS + .008 NITROGEN - .008 WEED
(5.70)*** (2.14)** (0.11) (1.72)*

+ .106 PREP + .029 RIDGE + .071 UNIV + .077 TENURE
(1.93)* (1.06) (2.13)** (2.34)**

+ .002 EXT - .108 ED*EXT
(1.07) (1.74)*

n = 125, R2 = .382

Note: Numbers in parentheses are t-values calculated using White's Heteroscedastic-Consistent Covariance Matrix method. *, **, *** indicate a significant difference from 0 at .10, .05, and .01 levels. YIELD = yield (natural log of kg/ha); DATE = planting date (log days after 1 Nov.); DURUM89 = dummy variable for variety and year (durum planted in 1989 = 1, others = 0); BREAD87 = dummy variable for variety and year (bread wheat planted in 1987 = 1, others = 0); DURUM87 = Dummy variable for variety and year (durum wheat planted in 1987 = 1, others = 0); PHOSPHORUS = dummy variable for phosphorus application (applied = 1, none = 0); NITROGEN = nitrogen applied (log of kg/ha); WEED = weed control (natural log of expenditure); PREP = land preparation (log of expenditure); RIDGE = dummy variable for planting method (ridge method = 1, others = 0); UNIV = dummy variable for education (university graduate = 1, others = 0); TENURE = dummy variable for tenancy (private operator or collective *ejido* = 1, individual *ejido* = 0); EXT = extension contact (number of visits per month); ED*EXT = interaction between education and extension (log of years of schooling times visits per month).

20 Dr. J.X. Ouvalle Bueno, CEVY soil scientist (pers. comm.).

yield response of 477 kg/ha to the application of 46 kg of phosphorus. The mean production elasticity for land preparation expenditures of 0.11 closely corresponds with profit maximization behavior.[21]

For the same levels of other inputs, university-educated farmers obtain 7% higher yields than farmers who have not graduated from university. The collective *ejidos* and private farmers obtain about 8% higher yields than the individual *ejidatarios*. Extension by itself appears to have a very small effect on yield, and education and extension are shown to substitute for one another.

The coefficient of primary interest is RIDGE, the ridge planting dummy variable. The estimated coefficient indicates that, holding all other inputs except seed rate constant,[22] the adoption of the new planting method provides a 3% yield advantage. This would increase net revenue by about 55,000 pesos/ha. The 3% estimate is reasonable, but the coefficient estimate is significantly different from zero at less than the 90% confidence level.[23]

The yield function estimate of the effect of ridge planting was verified with an *"ex-post"* partial budget using 1989 survey sample averages (Table 4.5). The partial budget shows a 40,000 pesos/ha cost advantage of ridge planting. This amount is nearly equal to the seed cost savings alone, with little difference in total weed control costs (41,000 vs. 38,000 pesos/ha). Farmers using the new planting method had a slightly higher average yield.[24]

There seems little question that the major advantage of ridge planting is that it reduces costs through lower seed rates and probably more efficient weed control. Whether ridge planting provides higher yields is more dubious. On the contrary, experiment station trials suggest a yield loss from ridge planting, with the amount of loss determined by the variety sown (K. Sayre, CIMMYT agronomist, pers. comm.). Whether these results can be extrapolated to farmers' fields, where seed rates, planting methods, weed control, and

21 At the mean, an increase of 1%/ha in expenditures on land preparation would cost 2,220 pesos and would increase revenue by 2,271 pesos/ha.

22 Seed rate was not included in the yield function estimation because of its high correlation with the planting method dummy variable.

23 A plausible explanation for the low significance level of the ridge planting coefficient is that information on the initial weed infestation level of surveyed fields was not included. The omission of a weed infestation variable from the specification has the effect of biasing the RIDGE coefficient downward (Traxler 1990).

24 The higher yield at equal weed control costs is consistent with the idea that weed control is more efficient under the ridge planting method.

irrigation methods are different, is not known. The economic benefits to ridge planting will therefore be calculated using the estimates above as well as an alternative estimate which assumes no yield advantage.

Diffusion of ridge planting — Farmers adopted the ridge planting method rapidly after the first extension bulletin on this practice was released in 1980 (Moreno, Salazar Gomez, and Mendoza 1980). Retrospective questioning was used to trace aggregate adoption levels through 1989. The steepness of the diffusion curve up to 1989 suggests that adoption will increase still further. Rapid adoption also verifies that farmers found the new planting method to be profitable. The adoption of this innovation in future years was forecast by fitting a logistic curve to adoption data for 1981-89, following Jarvis (1981). Equation 4.2 is the fitted equation under the assumption that 100% of farmers will eventually adopt the new planting method.

$$\log((P_t/(1.0 - P_t)) = -3.70 + 0.344t, \qquad (4.2)$$

where P_t is the percentage of farmers planting in beds in year t, and 1.0 (100%) is the assumed ceiling level of adoption. The observed adoption levels for 1980-89 and the fitted equation are shown in Figure 4.2.

The total area planted to wheat for the years up to 1989 was taken from official statistics published by the Ministry of Agriculture. To project future wheat area, an attempt was made to fit a univariate time-series model to the wheat area data for the 36 years up to 1989. Examination of the plotted data, autocorrelation function, and partial autocorrelation function for the series indicated that the series was stationary, with no significant autoregressive or moving average terms. Total wheat area in future years was, therefore, projected to be the mean area for the series (123,500 ha).

Table 4.5. Partial budget of benefits from ridge planting method

	Costs that vary (1989 pesos, 000s)	
	Traditional planting method	Ridge planting method
Seed	164	118
Land preparation	220	231
Herbicides	22	8
Hand weeding	21	12
Cultivation	0	18
Total costs that vary	427	387

Source: Adapted from Moreno, Salazar Gomez, and Mendoza (1980) using 1989 survey and price data.

Change in pest control practice — The IPM program has provided farmers with more precise information on pest populations and on the use of non-chemical means of pest control. This information has allowed farmers to reduce their reliance on insecticides for pest control. The intensity of insecticide use, however, is also affected by insect populations, which are in turn determined largely by stochastic weather events. Neither information on pest populations nor the yield impact of reduction in insecticides use is available.

Following the convention used by Reichelderfer and Bender (1979), Harper and Zilberman (1989), and Greene et al. (1985), an average value is assigned to the reduced application of pesticides based upon available information. No yield loss is assumed to result from the lower level of insecticide use. Fortunately precise information on both the share of farmers applying insecticides and the per-hectare expenditures is contained in the survey data, so the total reduction in insecticide expenditures on wheat in the valley can be easily estimated.

The annual value of the pesticide savings can be estimated as the average per-hectare expenditure times an area equal to 30% of the wheat area. For example, in 1989 insecticides were estimated to have been applied to 66,448 ha. If the IPM program had not been instituted, it was assumed that insecticides would have been used on 113,910 ha. At an average insecticide cost of 48,479 pesos/ha, there is a total change in the gross margin of approximately 2.3 billion pesos (US$ 900,000) for 1989. Sensitivity analysis will be used in the concluding section of this chapter to test the effect of the size of the assumed pesticide savings on the estimated rate of return to CMR.

Adoption and effects on total variable profit of both ridge planting and IPM are summarized in Table 4.6.

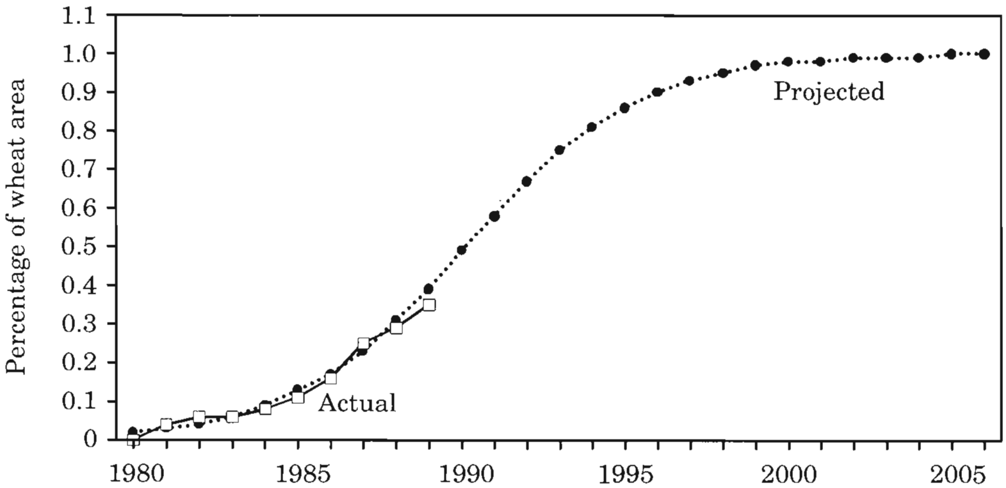

Figure 4.2. Actual and projected diffusion of ridge planting method, Yaqui Valley, Mexico.

Table 4.6. Estimated area on which crop management research recommendations are adopted and total changes in gross margin

	Ridge planting			Integrated pest management	
Year	Wheat area (000 ha)	Adoption area (000 ha)	Gross margin (billion 1988 pesos)	Adoption area (000 ha)	Gross margin (billion 1988 pesos)
1977	115	0	0.00	0	0.00
1978	110	0	0.00	0	0.00
1979	69	0	0.00	0	0.00
1980	127	0	0.00	0	0.00
1981	122	4	0.17	0	0.00
1982	153	9	0.34	0	0.00
1983	117	7	0.28	0	0.00
1984	126	10	0.38	0	0.00
1985	158	17	0.68	0	0.00
1986	156	25	0.99	0	0.00
1987	110	28	1.10	11	0.53
1988	130	38	1.52	26	1.26
1989	139	49	1.95	42	2.02
1990	143	63	2.50	43	2.09
1991	124	64	2.58	37	1.80
1992	124	75	3.00	37	1.80
1993	124	85	3.38	37	1.80
1994	124	93	3.72	37	1.80
1995	124	100	4.01	37	1.80
1996	124	106	4.24	37	1.80
1997	124	111	4.43	37	1.80
1998	124	114	4.56	37	1.80
1999	124	117	4.67	37	1.80
2000	124	119	4.75	37	1.80
2001	124	120	4.80	37	1.80
2002	124	121	4.84	37	1.80
2003	124	122	4.87	37	1.80
2004	124	122	4.89	37	1.80
2005	124	123	4.90	37	1.80
2006	124	124	4.91	37	1.80

Cost of the Crop Management Research Program

Research costs

The financial resources devoted to CMR and extension for wheat from 1977 to 1988 are calculated below, in order to provide an estimate of the overall efficiency of investments made in the total CMR program for wheat. Hence all expenditures on agronomic research — expenditures on research projects that led to useful innovations as well as expenditures on projects that did not — are included. By examining the whole research program, a more representative presentation of research efficiency is derived. Most studies examine only the returns generated by a single (invariably successful) research project.

Expenditures on CMR for wheat are not a conventional accounting category in the financial reports of CEVY, where research expenditures are reported according to disciplinary programs and commodity programs. Each type of program undertakes CMR. In the case of disciplinary programs that fit the classification of CMR — that is, entomology, weed science, soil science, water use and management, production systems, and climatology — expenditures on wheat CMR were estimated by assuming that the cost share to wheat within each discipline was equal to the proportion of experiments performed on wheat. Likewise, expenditures in the wheat research program were allocated between varietal development and CMR according to the number of experiments for each activity. In the absence of evidence that the cost per experiment differs substantially by crop or discipline, these calculations provide a reasonable estimate of CMR expenditures on wheat.[25]

Figure 4.3 shows CEVY's total research expenditures as well as expenditures for wheat CMR and for wheat breeding.[26] The Mexican economic crisis of the 1980s has placed the research station under severe budgetary pressure in recent years. Crop management research on wheat suffered most from budget cuts, falling from an average of 10% of total research expenditures prior to 1981 to just 4% in more recent years. In contrast wheat breeding maintained a relatively constant 8-9% of the budget share. Administrators clearly judged that crop breeding was a higher priority than CMR.

The cost of transferring crop management information

Advice from both private consultants and public extension agents was widely available to farmers in the study area. Annual extension expenditures were

25 A prorated share of the expenditures on plant pathology and the soil laboratory, based upon numbers of experiments performed, was also included in the calculation of wheat crop management expenditures.

26 All figures have been adjusted to December 1988 pesos using the national consumer price index.

approximated by assigning an annual value of 15,000 pesos/ha[27] (about US$ 6.00) to those farmers (over 80%) who reported receiving one or more extension contacts per month.[28] This value was based on the fee charged by private consultants, who are an important source of extension advice in the area. Since some extension advice relates to the choice of wheat variety, and some advice is probably independent of research findings, half of the cost of extension was assigned to transfer of the results of CMR. This resulted in an estimated total annual cost of extension services for CMR in 1989 of nearly one billion pesos (US$ 350,000). These figures suggest that extension expenditures are higher than research expenditures for crop management practices.

The Internal Rate of Return

The internal rate of return (IRR) to the investment in CMR was calculated using Equation 2.1 and then recalculated to test the sensitivity of the result to several key parameters. Key assumptions of the base model were conservatively established as:

1) The ridge planting method will eventually be adopted by 100% of farmers in the Yaqui Valley.

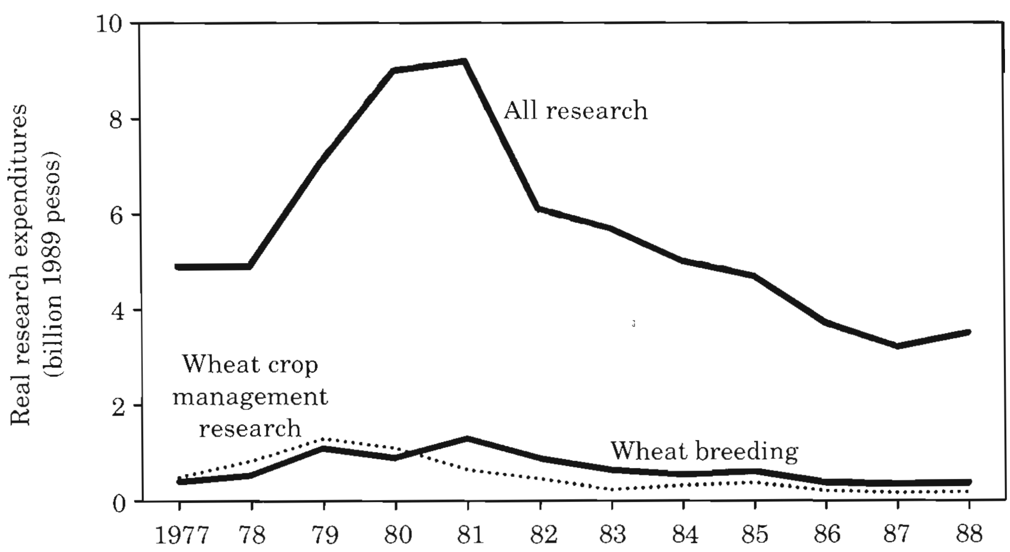

Figure 4.3. Real research expenditures by category for CEVY, 1977-88.

27 By comparison the public credit bank assesses a 3,500 pesos/ha fee to its clients for technical assistance. It is not known if this fee covers the full cost of the service.

28 A value of zero was arbitrarily assigned to those farmers who received less frequent contact.

2) Insecticide use declined by 10% yearly from 1987 to 1989, with the reduction remaining at 30% for all years after 1989. The reduced pesticide levels have no effect on yields.

3) Benefit streams continue until 2006 (30 years after the first CMR expenditure).

4) No maintenance research expenditures are incurred after 1987.

5) Extension costs related to CMR are equal to 50% of total wheat extension costs.

6) Extension costs begin two years after research costs and continue until 2006.

The base model produces an estimated IRR of 16%. The benefits from the change in planting method are large relative to other factors in this model (Figure 4.4.). The annual benefit from this practice is projected to grow for several years after 1989. The benefit flow from the adoption of IPM contributes much less to the total return since it is smaller and begins later in the study period. The CMR investment is relatively small, but obviously occurs several years before the peak in the benefit streams. The effect of extension expenditures on the IRR is important, since they are also assumed to have occurred before the benefit streams began.

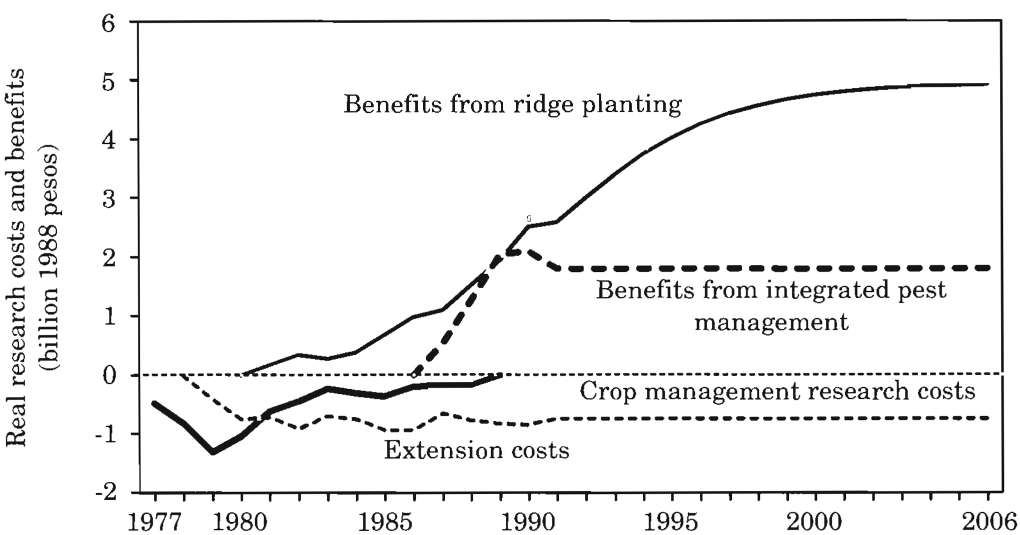

Figure 4.4. Estimated flows of benefits and costs to crop managenent research on wheat in the Yaqui Valley, Mexico.
Note: Benefits and costs after 1989 are projections.

The overall rate of return of 16% in real terms is probably higher than the opportunity cost of capital. However, it is somewhat lower than observed for other rate of return studies, which generally range from 20% to 40% (Ruttan 1982). This in part relates to the fact that we have chosen to evaluate the entire portfolio of research projects, many of which were not productive for the period under evaluation. We estimate that for the successful research projects that produced the entire flow of benefits (development of ridge planting and IPM), the rate of return was in excess of 100% for IPM and about 45% for ridge planting. The contrast in these IRRs demonstrates the bias inherent in choosing specific successful projects for evaluation.

The fact that a considerable amount of CMR was apparently unproductive argues for more careful monitoring of farmers' acceptance of CMR results (see Chapter 5). Such monitoring is already done in many countries to assess the adoption of new varieties developed by plant breeding programs (see Dalrymple 1986).

However, many of the assumptions listed above are conservative, and sensitivity analysis was used to explore variation in the assumptions. The elements chosen for evaluation were the following:

1) The share of extension costs assigned to CMR.

2) The level of reduction in pesticide use resulting from the IPM program.

3) The aggregate adoption ceiling of the ridge planting method.

4) The inclusion of maintenance research costs.

The appropriate share of the total extension expenditure to be borne in the CMR effort is not clear. The base model assumed that half of this extension effort was directed at activities unrelated to CMR findings. The sensitivity of the model to the assumed extension burden was tested by calculating the IRR with no extension costs assigned. The model is relatively sensitive to this change, increasing the IRR to 23%.

The sensitivity of the model to the assumed level of reduction in insecticide use was also tested by assuming that IPM leads to a 50% reduction in insecticide use. Since the benefits from IPM accrue relatively late in the study period, the IRR is insensitive to this benefit stream, rising by 1.5%.

A ceiling level of aggregate adoption of 100% was assumed in the base model. A diffusion curve was estimated using an assumed ceiling adoption level of 80%. Since changes in this parameter only affect benefits occurring after 1989, the IRR was reduced by only 1%.

It is not unreasonable to think that some research may be needed to maintain the effectiveness of the new practices. This is especially true for IPM, since pest resistance and insecticides can be expected to evolve. Little research has been done on the importance of maintenance research costs for either crop management or crop breeding research. To test the effect of maintenance research costs, an IRR was calculated assuming that CMR investments equal to 50% of the average annual expenditure from 1986 to 1988 would be needed for all future years. The IRR is also insensitive to this future cost stream, changing by less than 1%.

The sensitivity analysis resulted in IRR estimates ranging from 11% to 23% (Table 4.7). The model was most sensitive to the assumption concerning the appropriate assignment of extension costs. The assignment of maintenance research costs and the level of pesticide savings have only modest impacts on the model.

Table 4.7. Sensitivity of internal rate of return to model assumptions

	IRR (%)
Base model	
50% of extension costs assigned to CMR 100% ceiling diffusion for planting method 30% gain in insecticide use efficiency No maintenance research required	16
Alternate assumptions[a]	
100% of extension costs assigned to CMR	11
No extension costs assigned	23
50% gain in insecticide use efficiency[b]	18
Maintenance research required[c]	16
80% diffusion ceiling for planting method[d]	15

[a] Sensitivity analysis varying one assumption at a time.
[b] IPM program assumed to reduce insecticide use by 30% in 1987, 40% in 1988, and 50% in all subsequent years.
[c] Assumes that in the years from 1989 to 2006 a research investment equal to one-half of the average research expenditures in 1985-87 will be required to maintain the effectiveness of IPM and ridge planting.
[d] Ridge planting is assumed to follow logistic diffusion path with a ceiling diffusion level of 80% of total wheat area.

5

Monitoring the Impacts of CMR

The evidence presented in this paper suggests that monitoring and evaluation should be an integral part of any CMR program. While it may be useful to conduct comprehensive cost-benefits analysis of a CMR program, this is advisable only for special studies, perhaps every 5-10 years for a given station. Rather, each CMR program should regularly assess changes in farmers' practices, pest populations, and variables measuring changes in resource quality for the target area of the research program. This type of monitoring can serve two major purposes: continuous diagnosis and monitoring adoption of technology.

Where farming systems are evolving rapidly, as in post-Green Revolution agriculture, information from the initial diagnosis quickly becomes outdated (Maxwell 1986). This rapid evolution of farming systems results from a number of factors characteristic of these systems (Byerlee 1987):

a) Changes in the economic and technological environment that stimulate rapid adoption of new cropping systems. The dramatic spread of the rice-wheat, soybean-wheat, and cotton-wheat double cropping systems over millions of hectares in South Asia over the past two decades is evidence of these kinds of changes.

b) Rapid adoption of new technologies that have important implications for the farming system as a whole. For example, the adoption of a new early maturing Basmati rice variety on 70% of the rice area in the Punjab of Pakistan from 1986 to 1988 had important implications for land preparation and planting date for the wheat crop that followed rice (Sharif et al. 1991).

c) Changes in the quality of the resource base, such as levels of soil fertility, salinity, and organic matter or the depth of the water table. These factors are important as we give more emphasis to longer run sustainability issues in CMR.

d) Changes in pest populations, such as a new weed spectrum, perhaps as a result of changes in cropping patterns or practices in (a) above. For example, in Mindanao, Philippines, new weed spectra have been observed after only two years of chemical weed control on maize (Oliva et al. 1990).

Given these types of changes, researchers clearly need to continually update research priorities, both for on-farm adaptive research as well as for applied research on experiment stations, such as plant breeding.

It is also important to monitor the adoption of technology to provide feedback to scientists and research administrators on the successes or deficiencies of research programs. Such information is increasingly necessary to researchers, who must demonstrate the impact of their work and justify research expenditures. Given the importance of monitoring in CMR, the remainder of this chapter discusses methodological issues.

Methodological Issues in Designing a Farmer and Field Monitoring System

Continuous monitoring involves significant cost outlays (see the next section). Any monitoring system must be designed carefully to provide the minimum information of sufficient quality to satisfy researchers' objectives. The major methodological issues that need to be considered in designing a monitoring system are the variables to be collected, the frequency of the survey, and the sample size and method.

The variables to be collected
Several categories of variables may be collected, involving somewhat different costs and levels of difficulty.

Farmers' key practices — The most important category of variables in any monitoring survey is data on key practices such as variety sown, planting date, crop rotation, and fertilizer and pesticides applied. Many other variables, including tillage practices, irrigation practices, and turnaround time between crops might be added depending on the system under study. In general, data on farmers' practices are the cheapest and easiest to collect. The surveys described in this study engaged one or two field assistants for up to one month in each year that a survey was carried out.

Inputs and outputs — If a full farm management accounting is required (e.g., to measure changes in total factor productivity), data on machinery and labor costs as well as crop yield will be required. These data should be collected at the field level rather than taking the farm-level approach common to farm management surveys.

Quality of the resource base — Researchers have little experience with monitoring variables to measure changes in resource quality although these variables are critical to monitoring the sustainability of a system. At the very least, regular soil testing over time is needed. While not inherently difficult to obtain, reliable soil test data require a well-conceived field sampling design and good soil laboratories.

Pest populations — Again, there is relatively little experience with monitoring this type of variable over time. Costs of estimating pest populations generally depend on whether a subjective scoring method or objective quantification is used (Byerlee, Triomphe, and Sébillotte 1991). Subjective scoring requires careful calibration among researchers. In the case study in this paper, subjective scoring of grassy weed problems was part of each survey.

Frequency of monitoring

A key question in any monitoring system is how frequently to visit farmers and their fields. The frequency of monitoring is influenced by three considerations:

- Frequent visits (more than once per crop cycle) can be quite expensive and should be justified with care. It is desirable, however, to collect a minimum data set annually for each major crop in the cropping pattern. Less frequent monitoring can still provide valuable information, especially in irrigated areas, as shown by this study. However, without annual data it is sometimes difficult to distinguish between longer term trends, which are of interest in monitoring research impacts, and short-term fluctuations caused by variability in weather or the economic environment.

- Not all variables need to be collected on every visit. For example, if one objective of the monitoring is to determine trends in soil organic matter levels, soil sampling at intervals of several years may be sufficient.

- Limited resources mean that a tradeoff is usually made between in-depth monitoring of a small sample of farmers and/or fields and less frequent visits to a larger sample. We favor the latter strategy as most appropriate for a CMR program.

Sampling issues

Given the particular objectives of monitoring, the field rather than the farmer should be the sampling unit. Certainly monitoring variables such as soil fertility and pest populations have little meaning at the farm level. A new sample may be selected every year or the same fields may be visited again over time. Repeated visits to the same farmer and field have two main advantages:

- Changes in practices and resource quality can be tracked more accurately over time through pair-wise comparisons at two points in time for the same field.

- Once the initial cost of constructing a sample frame, selecting a sample, and contacting the farmers has been made, the cost of repeated surveys is greatly reduced. Also, rapport with farmers can be established through long-term contact, increasing the confidence in the data.

At the same time, some precautions should be taken in repeated sampling:

- A sufficient number of fields should be selected to allow "dropouts" in future visits because of a change in cropping pattern in some fields. Nearly one-third of the fields examined in this study were rotated out of wheat in a given year.

- The location of fields and farmers should be documented carefully, preferably by mapping or the use of GPS (Global Positioning System) for precise measurement of latitude and longitude coordinates, so that when research staff change, new staff can readily locate the same fields and farmers.

- Since the sample design is intended to provide information over many years, it is important that considerable thought be invested at the beginning in ensuring that sample size, representativeness, stratification, etc., are adequate to meet the objectives of the monitoring exercise.

As in any kind of survey, for a monitoring survey sample size will be guided by cost considerations and the heterogeneity of the system under study. Experience from this study suggests that, even for a single cropping system, a sample of less than 100 fields is often inadequate once within-system heterogeneity is considered (e.g., soil type, farm size, access to irrigation) and dropouts due to crop rotation are allowed for. In most cases, it is better to monitor one major system well than to cover all systems within the domain of the research program.

Data storage and retrieval
Even when a system is established for regularly collecting data on farmers' practices, data for each year must be stored in such a way that it can be readily accessed and merged with results from previous years. For this study, each farmer was assigned a unique identification, all data were entered in SPSS (Statistical Package for the Social Sciences), and a separate file was maintained for each survey. Hence data for any one survey year can be easily accessed and data across years can be analyzed readily by merging files.

Cost Considerations

The major cost consideration in designing a monitoring system will be the resources available for travel and *per diem* costs to visit farmers' fields. Each research program will have its own cost considerations, but some general guidelines can be identified.

First, monitoring must be considered a priority activity. Too many research systems operate in an information vacuum that reduces the effectiveness of costly experimental programs. Monitoring can help identify ineffective CMR projects and reduce research costs (for example, research on fertilizer use in the present study). If a CMR program is effective, as demonstrated by farmer adoption, the results from monitoring farmers' adoption of recommended practices should help justify research budgets. Second, most CMR involves *ad hoc* surveys, but results across surveys often cannot be compared. A well-developed monitoring system could substitute for *ad hoc* surveys and at the same time provide more comprehensive and consistent information to various users. Third, only limited resources are required for regularly collecting a minimum data set (e.g., farmers' key practices). Given the low cost and potentially high benefits of monitoring farmers' practices and fields, monitoring should be an integral part of any CMR program.

6

Conclusions

In an effort to fill a gap in the literature on technical change in agriculture, this study has developed a method for evaluating CMR programs and has produced an estimate of the economic surplus generated by a CMR program in the Yaqui Valley of Mexico.

Measuring Returns to CMR

The experience of this study suggests that the returns to CMR can generally be computed by following a logical sequence of steps:

1) Identify the products of CMR, which are usually best represented by changes in recommendations.

2) Identify changes in farmers' practices which are consistent with changes in recommendations.

3) Establish causality between the change in farmers' practice and a change in recommendation.

4) Measure the impact of each research-induced change in crop management practice on economic surplus.

5) Sum the economic surplus across practices and compare the benefit stream to the costs of CMR and extension.

The analyst is likely to find two major difficulties in implementing this sequence. First, unless regular statistics are collected on farmers' practices, it will be difficult to identify changes in continuous practices such as fertilizer level, seed rate, or plant density. For discrete practices such as a new tillage method or new purchased input, retrospective questioning should enable the adoption path to be estimated. A more comprehensive analysis, including changes in continuous practices, will require regular monitoring of farmers' practices as described in Chapter 5.

Second, because changes in crop management practices can result from sources other than CMR such as extension, the private sector, or changes in policy, a critical step is to estimate changes in practices in the absence of the CMR program. In this study it appeared extremely unlikely that in the absence of CMR the new planting methods or IPM would have been adopted during the period of analysis. In other instances, for example when fertilizer levels change in a way consistent with the change in recommendations, it may be very difficult to establish causality, let alone the evolution of practices in the absence of CMR. The best approach is probably to perform sensitivity analysis with respect to changes in practices with the CMR programs.

Finally, this study emphasizes the need for the analysis to encompass an entire CMR program. It is tempting to choose a successful case study of a particular CMR project for computing returns to research, but this choice may provide misleading information to research managers unless the cost of research resulting in "dry holes" is also considered.

Despite these caveats, we now feel confident that it is possible to compute returns to CMR by carefully applying the sequence of steps listed above.

Are the Returns to CMR Generally High?

This final section addresses two important issues about CMR. First, how robust is the conclusion that CMR represents an efficient use of public funds? And second, what are the important determinants of the efficiency of CMR expenditures, and how might the return on investment be improved?

Since this is the first study to estimate the return to a CMR program, it is important to keep in mind the characteristics of the study area when attempting to generalize the findings. The capability of CEVY's scientific staff is impressive. Furthermore, CEVY and CIMMYT researchers have a long history of association. The Yaqui Valley also benefits from a dense network of extension support, including private extension services.

A robust conclusion concerning the return to CMR cannot be based upon the results of a single case study. General acceptance that the return to crop breeding research is high has come only after dozens of studies (see Bengston 1985, Pinstrup-Andersen 1982, or Ruttan 1982). These studies have been accumulated over 30 years, and it is unlikely that a comparable number of CMR studies will be available soon. However, based on the literature, two conclusions can be made about returns to CMR.

First, the *ex-ante* studies on the economics of continuous response research find the potential per-hectare value of response information to be low due to the smoothness of the profit surface over a wide range of dosages (Havlicek and Seagraves 1962; Anderson 1968, 1975; Anderson and Dillon 1968; Byerlee and Anderson 1969; Colwell 1970; Doll 1971, 1972; Ryan and Perrin 1974; Perrin 1976; Drynan 1977; Mjelde, Sonka, Dixon, and Lamb 1988; Mjelde, Dixon, and Sonka 1989).[29] It was not surprising, therefore, that this study found no benefits to have been generated by continuous response experiments (on nitrogen, phosphorus, seeding rates, planting dates) in the Yaqui Valley. Anderson and Dillon (1968) emphasize that more experimentation is not always better, since research resources must be evaluated according to the same

29 Only Ryan and Perrin (1974) find a large per-hectare value, but it is the result of a switch from a farm average fertilizer dosage of 10 kg/ha to 400 kg/ha.

criteria as other agricultural inputs (that is, the marginal value product must at least equal the cost of the resources consumed). It is hard to escape the conclusion that this principle is routinely violated in many research institutions. There would seem to be few remaining agricultural areas of the world where valuable information is provided by additional response trials, given the accumulated knowledge which has been generated, farmers' own trial and error experimentation, the variability in crop response among and even within fields, and the difficulty of transferring complex crop response information to farmers.

On the other hand, the returns are potentially high to CMR that generates new practices which are widely adopted by farmers. Published CMR project evaluations by Martínez and Sain (1983), Doelman (1989), and Norgaard (1988) demonstrate that high-payoff CMR projects exist. In this study, the benefits generated for the development of ridge planting and IPM in the Yaqui Valley were sufficient to cover the cost of the entire CMR program. Both practices were developed through complex and innovative research projects carried out by well-trained scientists. However, the rate of return to any research program is a weighted average of the returns to individual projects. For a program to generate a favorable IRR, the "overhead" of projects generating low returns must be offset by projects that generate high payoffs. It can be argued, for example, that continuous response research is an overhead expense that could be reduced in many CMR programs.

With this simple model of investment returns in mind, we could ask what one would find if a larger sample of CMR programs were examined. The average return to CMR would be high only if: 1) the pool of high-payoff CMR projects was large or 2) researchers were very efficient at distinguishing beforehand between high- and low-payoff CMR activities. At this point, the information is insufficient for judging how frequently either condition is satisfied. We do hypothesize that there may be more variability in the IRR of agronomic research investments than for crop breeding. Our experience would suggest that a great deal of CMR is unproductive for two reasons. First, the products of CMR are not relevant to farmers, either because they do not address farmers' needs or because the products have not been evaluated under farmers' conditions. The need to correct this deficiency became a major impetus for the emphasis on a farming systems approach to research in the 1980s. Second, even if CMR products are relevant to farmers, institutional infrastructure in the form of input suppliers and extension is often unable to deliver the product to the farmer. New varieties, the products of plant breeding, can often diffuse from farmer to farmer, especially in the case of self-pollinated crops such as wheat and rice. But CMR products largely take the form of new inputs or information and greater institutional support is needed for farmers to become familiar with them. The site-specific nature of much CMR also poses challenges to increasing its payoff. This study contends that the adoption of CMR products is often conditional on appropriate extension advice.

One interpretation of the success of the international agricultural research centers (IARCs) is that they constitute a very efficient international system for the delivery of intermediate germplasm technologies. The centers are, in effect, centralized institutes with access to large pools of scientific talent and germplasm banks, creating an economy of scale that need not be replicated in each country of the world. As a result, plant breeders in national agricultural research systems have access to elite germplasm that is the product of thousands of crosses and verification trials, which considerably increases the odds of discovering a material that is locally adapted and superior to previously released varieties.[30]

The IARCs produce a much smaller stream of "high probability" crop and resource management technologies. This is so largely because of the nature of crop management innovations, including their greater agroclimatic specificity, but also because the international centers (at least CIMMYT) devote relatively fewer resources to agronomic research. While the structure of the germplasm delivery system does not serve as a precise blueprint for linking CMR in national and international research institutes, considerable scope exists for IARC intervention in developing appropriate crop management technologies through regional collaboration.[31] This would likely require the development of a higher level of scientific capital within the developing country national research systems themselves.

Despite these observations about the lack of generality of our conclusions on the economic returns to CMR, we believe that CMR will play a greater role in future increases in productivity. It is significant that both of the successful innovations identified in this study increase productivity by increasing input efficiency (in the case of IPM, by substituting better information for inputs). As much of the developing world's agriculture moves into a post-Green Revolution phase of development, there will be increasing opportunities for CMR to provide improved information to enhance input efficiency and system sustainability.

30 See the probabilistic model of the research discovery process presented by Evenson and Kislev (1975).

31 Anderson, Herdt, and Scobie (1986) provide a few example of successful IARC-generated crop management innovations.

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