Economic Returns to Crop Management Research in a Post-Green Revolution Setting

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Returns to research studies have neglected research on crop management (CMR), which may account for half of all crop research. Because CMR enhances the efficiency of input use, returns to CMR are hypothesized to increase in settings characterized by high input levels and high yields. A method is developed to estimate returns to CMR, and this method is applied to wheat research in a post-green revolution setting in northwest Mexico. The results suggest that returns to CMR are positive over a range of model assumptions.

Key words: crop management research, Mexico, returns to research, wheat.

Studies of returns to research tend to estimate returns for the aggregate research system or for all research on a specific commodity. At the subcommodity level, there is a clear bias toward estimating returns to plant breeding research aimed at developing improved varieties (e.g., Nagy and Furtan; Ayer and Schuh; Ardito-Barletta; Akino and Hayami). However, despite all this "research on research," one major type of crop research has been ignored: research on crop management. This activity is defined here to include all crop-related research not aimed at varietal development—that is, research on crop husbandry (e.g., seeding rates, planting dates, and tillage methods), pest management (e.g., method and timing of weed control), and resource management (e.g., irrigation scheduling). Crop management research (CMR) is estimated to account for about one-half of all investment in crop research.[1]

The first objective of this study is to develop and test a systematic yet simple method for conducting an *ex post* evaluation of an entire CMR program, as opposed to evaluation of an individual CMR project as in previous studies (e.g., Norgaard; Martínez and Sain). A second objective is to test the hypothesis that returns to CMR are high in a typical post-green revolution setting. During the past two decades, gains in agricultural productivity have resulted primarily from plant breeding research—specifically, the development and adoption of high-yielding semidwarf wheat and rice varieties—accompanied by improved supplies of irrigation water and increasing levels of chemical fertilizer and other purchased inputs. Much of the developing world, especially in Asia, has now entered a post-green revolution stage of development in which the adoption of these inputs is high and the returns to more intensive use of inputs are diminishing (Byerlee). Hence future productivity gains are likely to result from using improved information and management skills to substitute for higher input use and to promote greater input efficiency. Crop management research programs can be a major source of the information needed for this transition to more efficient input use. In this paper, the methodology developed is applied to test the hypothesis of high returns to CMR in northwestern Mexico, where the green

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[1] In Mexico and Central America, for example, between 36 and 55% of crop research expenditures are associated with crop management disciplines (Cuevas-Perez, Zeigler, and Sanint; Polanco). Araji reports that between 1951 and 1986 an average of 78% of the annual public wheat research expenditures in the western United States was allocated to crop management research, as were 45% or all expenditures of the Mexican research station examined in this study.

revolution in wheat originated some 30 years ago and where farmers now use high levels of inputs and obtain high yields.

Conceptual Framework

Following the definition of CMR given above, it is reasonable to assume that for each operation in the production of a crop, a CMR program has the potential to produce multiple products related to the type of input, its dosage, and the time and method of application. In some cases, the product of CMR might be a new input, such as a new pesticide, but usually the product is improved information. Moreover, most new inputs are developed by the private sector, whereas the public sector (the focus of this study) generally produces improved information.

Improved information is a much less tangible output of research than a new product or technique, which raises the question of how to measure the output of CMR. Even if a suitable means of measuring CMR output can be obtained, the question of how to measure the impact of the new information must be answered. These difficulties are not so great for crop breeding programs, because the products of plant breeding are easily identified (new varieties), and their impact can be measured in terms of the adoption of new varieties and the resulting effect on crop yields.

Evaluating the economic returns to CMR is also complicated because alternative sources of supply may exist for information on improved crop management practices—the public sector, the private sector, the extension service (independently of CMR), and farmers' own experience and informal experimentation. Although the role of better information (provided by extension services) and skills (learned through education) in increasing farmers' efficiency has been widely recognized (Huffman 1977), the contribution of public sector CMR versus other potential sources of these skills and information has not been analyzed.

We propose that the impact of a crop management research program can be evaluated in five logical and sequential steps, as follows. (*i*) Identify the research areas for which an improved management practice has been embodied in a new recommendation (i.e., new information) issued to farmers. (*ii*) Determine the practices for which producers have modified their management in a manner consistent with the new recommendation. (*iii*) Determine whether the revised recommendation has been the cause of the change in farmers' practices. (*iv*) Measure the impact of each research-induced change in crop management practice on economic surplus. (*v*) Sum the economic surplus across practices and compare the benefit stream to the total costs of the crop management research and extension program.

The first three steps present conditions which should hold in order to link a given research thrust to an increase in economic benefits. A research thrust that fails to meet any of these conditions cannot be judged to have had an impact on economic surplus.

The first step makes use of a simple indicator of the products of CMR. Most research stations periodically prepare and distribute detailed recommendations for producing a given crop. It is reasonable to assume that new innovations and information emanating from CMR are embodied in changes over time in these recommendations.

The second step assigns an economic value of zero to CMR that leads to changes in recommendations that farmers do not adopt, for whatever reason (e.g., lack of access to complementary inputs or recommendations inappropriate to the farmers' situation).

The third step requires evidence of causality between the CMR effort and changes in farmers' practices. This condition is necessary because changes in farmers' practices may result from information developed by farmers' own learning-by-doing, information from other sources such as the private sector, or from changes in the policy environment.

The last two steps in the analysis of returns to CMR calculate the total change in economic surplus induced by the research. Following standard theory, the size and distribution of the surplus generated by agricultural research is determined by the magnitude of the induced shift in the supply curve and by the elasticities of supply and demand. Since CMR is a relatively site-specific activity and each research station issues recommendations for specific production zones, it is possible to assume the "small country" case of perfectly elastic demand so that changes in consumers' surplus need not be considered. Likewise, production inputs can be assumed to be available in perfectly elastic supply. These assumptions imply that producers' surplus and quasi-rent (total revenue less variable costs) are equivalent measures (Just, Hueth, and Schmitz), allowing changes in quasi-rent to be estimated using enterprise budgets or primal methods.

Given the change in gross margin per unit of area, $\Delta\pi_i$, the annual value of an improved practice is given by

$$(1) \qquad Q_{it} = A_t \Delta\pi_i (k_{it}^* - k_{it}^0),$$

where Q_{it} is the total quasi-rent generated by innovation i in year t, and A_t is the total harvested area of the crop of interest in year t. The term, $k_{it}^* - k_{it}^0$, represents the difference between the percent adoption of the innovation in year t in the presence of the CMR program (k_{it}^*) and the adoption of the innovation that would have occurred without the CMR program (k_{it}^0). For many innovations it is possible that extension services, farmers, or the private sector could eventually develop the new information without CMR (Martínez and Sain). The benefit 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.

Since our objective is to estimate the overall efficiency of investments made in a CMR program, all expenditures on CMR—expenditures that led to useful innovations as well as expenditures on research that proved unsuccessful—are included. The decision to include all expenditures contrasts with methods used in other studies, which examine only the returns generated by a single, usually successful, CMR project. Because it is impossible to predict which research projects will be successful, evaluating the entire portfolio of projects chosen by a research station's administrators gives a more representative estimate of the returns to investment in CMR.

In measuring returns to CMR, the cost of transferring the improved information through extension should usually be considered. The speed of adoption and successful use of improved technology has been found to be conditioned by the quantity and quality of extension services (Huffman 1978). Extension is particularly important in disseminating the products of CMR, which take the form of improved information whose value depreciates as it is transferred from farmer to farmer (Byerlee and Heisey). Because partitioning the effects of research and extension would be artificial, an alternative and more appropriate assumption is that the returns to CMR are conditional on the availability of extension advice.

The Study Area

The framework described above was used to evaluate the returns to CMR on wheat in the Yaqui Valley of northwestern Mexico. Wheat is the main crop in the system and is grown on an average of 120,000 ha each year. Wheat production in the Yaqui Valley is a mechanized, high-input activity and all wheat is irrigated. Average yields of over 5 t/ha make the Yaqui Valley one of the highest-yielding wheat areas in the developing world. Nonetheless, in recent years the rate of genetic gain in yield has slowed and average gains in farmers' yields have fallen from an annual rate of 5.1% between 1951–1972 to 1.3% since 1973. Because slower rates of growth in yields are likely to remain the norm, future gains in productivity will depend increasingly on using inputs more efficiently.

The valley is served by a single research station of the Mexican national system, the Yaqui Valley Experiment Station (Campo Experimental del Valle de Yaqui, or CEVY). This station releases new wheat varieties continuously and conducts an active program of CMR which influences nine general management practices: planting method, planting date, land preparation, nitrogen use, phosphorus use, irrigation management, weed control, insect control, and harvesting technique. The research station has an active program for transferring new technology to farmers through field days, extension bulletins, and frequent contact with a dense network of private and public extension agents.

Data for this study were obtained from four detailed farm surveys conducted in the Yaqui Valley in the 1980s. The surveys employed a two-stage random sampling procedure to select 84 farmers in 1981, 63 in 1982, 41 in 1987, and 101 in 1989. The basic unit of analysis is an individual field, which can range from 3 to 60 ha. The 1989 survey assembled information on education, extension contact, and farmers' other sources of technical information. Additional details on the data and analysis are contained in Traxler and Byerlee.

Estimating the Model's Parameters

The five-step procedure was used to measure returns to investments in the CMR program conducted by CEVY from 1977 to 1988. Selection of this time period was based on available data on research costs. Results of the analysis for each of the five steps are described below.

Changes in Recommendations

A wheat production guide is widely distributed to farmers and extension workers in the Yaqui

Table 1. Summary of Changes in Crop Management Practices 1981–89

	1981	1982	1987	1989	Test statistic[a]
Soil preparation:					
% subsoiling clay soils	32	na	36	23	1.8(2)[b]
Planting method:					
% using ridge method	8	5	37	33	44.6*(9)[b]
Seeding rate:					
ridge method (kg/ha)	76	75	122	125	14.3*(287)[d]
traditional method (kg/ha)	163	156	175	175	
Planting date:					
median date	5 Dec	9 Dec	10 Dec	6 Dec	1.1(3)[c]
Fertilizer use:					
nitrogen (kg/ha)	176	194	218	230	30.7*(3)[c]
phosphorus (% applying)	59	56	83	78	16.9*(3)[b]
Insect control:					
% applying insecticide	82	64	27	56	39.1*(3)[b]

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

Valley (CEVY). This guide is updated each year to incorporate results of research from previous crop seasons. Changes in recommendations appearing in the guides between 1977 and 1988 were used to identify the output of the CMR program. Significant changes in the recommendations for three practices (planting method, phosphorus use, and insect control) were identified, along with minor modifications in recommendations for three other practices (land preparation, nitrogen use, and planting date). The recommendations for weed control, harvest method, and irrigation management remained essentially unchanged over the period of analysis.

Changes in Producer Practices

Several important changes in crop management practices in wheat were identified through the farm surveys conducted in the 1980s (table 1). Farmers used larger quantities of fertilizer in 1989 than in 1981. The average application of nitrogenous fertilizer increased by 30%, and the proportion of farmers applying phosphorus increased by about 20%. A significant decline in insecticide use was also observed.

A new method of planting wheat on ridges also diffused rapidly in the 1980s. This method involves planting wheat as a row crop on ridges 75 cm wide (usually with two rows of wheat per ridge), rather than by the conventional methods of broadcasting the seed or drilling in rows of about 20 cm width. In the high-yielding, high-input environment of the Yaqui Valley, this planting method reduces costs, partly because mechanical cultivation is used in place of herbicides, and partly because it allows a 30% lower seeding rate (about 50 kg/ha less).

The farm survey information was used to examine statistically the distributions in each year of those practices for which new recommendations had been issued. Wheat management practices are of two types: practices that take continuous values (e.g., nitrogen use), and discrete practices which are identified only on the nominal scale (i.e., adoption of one of three planting methods). The distributions of continuous practices were examined using the nonparametric Friedman rank test to test the null hypothesis that the populations representing the characteristic of interest (e.g., nitrogen dose) are distributed identically in each year that a sample was drawn. The distribution of the test statistic approximates a chi-square. For discrete practices, the null hypothesis is that in the sampled population, the proportion of farmers applying the practice of interest is equal in all years. A chi-square test was used to test this hypothesis.

Results of these tests (table 1) suggest that farmers made significant changes over the period 1981–89 in four of the six practices identified in the first stage of analysis (i.e., practices for which CEVY had changed its recommendations). These four practices were the use of nitrogen, use of phosphorus, insecticide application, and planting method. For the two remaining practices—planting date and land preparation—there was no significant change in farmers' practices.

Evidence of Causality Between Recommendations and Practices

Nitrogen and phosphorus use. Compelling evidence exists that changes observed 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 precede application, yet this suggestion was followed by only 13% of producers in 1989. Nor was there any relationship between the amount of nitrogen recommended and applied. The recommendations given for nitrogen use are conditional on each soil type, planting date, and rotation. The correlation between recommended and applied nitrogen amounts for the four survey years were 0.07, −0.02, −0.12, and −0.03, suggesting that no linear relationship exists. On average, farmers were observed to have moved farther from the recommended dose over time and by the end of the period were, on average, using nearly double the recommended dose.

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). An effort was also made to extend the new practice to farmers through demonstrations and field days. By 1989, ridge planting had been adopted by 33% of farmers.

Insecticide use. The evidence that information can substitute for the use of chemical inputs in insect control is well established (e.g., Feder; Taylor), especially through programs of integrated pest management (IPM). These programs use information, such as information obtained from observing pest and predator populations, to reduce the demand for prophylactic applications of pesticide. IPM research at CEVY began in 1983; this work focused on aphid control (J.L. Martínez Carrillo, personal communication). 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 newspapers were also used to give producers weekly estimates of pest and predator populations.

To see if there was evidence of a direct link between the CEVY research program and reduced use of insecticide, 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. In 1989, 82% of farmers stated that they were less disposed to use chemical control 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; only 3% said that they used pesticides to prevent future pest attacks; and 75% stated that they apply insecticides only after consulting with extension personnel. On the basis of this subjective evidence, the IPM research program seems to have resulted in a significant decrease in insecticide use.[2]

Estimated Changes in Quasi-Rent

The analysis up to this point is summarized in table 2. Although CMR changed recommendations in six of the nine practice areas for which research was conducted, farmers made changes in just two practices—planting method and insecticide use—as a result of the CMR effort. The final step in the analysis is to estimate the change in profit expected from the adoption of these two innovations.

The two innovations (ridge planting and IPM) have changed the way adopting farmers control weeds and insects. Econometric estimation of the impact of such "damage abating" innovations is difficult because of the type of information required on pest populations (Lichtenberg and Zilberman). Since this information was not available in the data set, partial budgeting was employed to estimate the cost savings from adopting the recommended practices, assuming no change in yield.

The impact of the IPM program was quantified by assuming that yields have not been affected by the reduction in insecticide use and using point estimates to calculate the savings in insecticide costs (Greene et al.). An average of 73% of farmers applied insecticides in the two survey years before the change in recommendation occurred, versus 42% in the two surveys

[2] An attempt was also made to relate the probability of insecticide use to research and extension contact by the estimation of a probit model. Although the variable for research/extension contact had the anticipated negative sign, it was nonsignificant, probably because of lack of detailed information on the level of pest infestation, which is likely to be the major variable influencing insecticide use.

Table 2. Summary of Conclusions Concerning Induced Changes in Farmers' Practices as a Result of CMR

Practice	Change in recommendation?	Change in practice by farmers?	Causality between change in practice and CMR?
Weed control	No	—	—
Irrigation	No	—	—
Harvest	No	—	—
Land preparation	Minor	No	—
Planting date	Minor	No	—
Nitrogen	Minor	Yes	No
Phosphorus	Significant	Yes	No
Planting method	Significant	Yes	Yes
Insect control	Significant	Yes	Yes

conducted after the change in the recommendation. The point estimate, therefore, is that insecticides are now used on 30% less of the total wheat area than before the IPM program was initiated. Average per hectare expenditure for farmers who applied insecticides in 1987 or 1989 was 48,500 pesos (P) in 1989 prices, or about $US 17. Applying these savings over 30% of the wheat area for all years after 1986 gives a total annual savings of US$ 612,000.

The quasi-rents from ridge planting were estimated by constructing enterprise budgets for adopters and nonadopters using average yield and expenditure figures from the 1989 survey. Given that no significant yield difference was observed between ridge planting and the traditional planting method, all the benefits to the new planting method are assumed to result from cost savings in lower seed rates and in weed control. The point estimate is that gross margins have increased by approximately P 40,000/ha (US$ 14.80).

The field surveys indicated rapid adoption of ridge planting following the release of the first extension bulletin on the practice in 1980 (Moreno, Salazar Gomez, and Mendoza Mendoza). This suggests that farmers found the innovation profitable and that aggregate adoption will continue to increase. To calculate the total benefits attributable to the innovation, it is necessary to estimate adoption for both survey and non survey years prior to 1989, as well as to project future adoption. Previous studies (Griliches, Jarvis) used econometrically estimated logistic diffusion curves of the basic form given in equation 2 to model the diffusion process.

$$(2) \qquad \log (S_t/(C - S_t)) = \alpha + \beta t,$$

where t = (year-1980), S_t is the percent of farmers using the innovation in year t, α and β are estimated parameters, and C is a ceiling level of diffusion determined by estimating the model for parametrically varied assumed ceiling values and choosing the model with the highest R^2 (Jarvis).

Because the four field survey observations allowed a small number of degrees of freedom for estimating the two parameters of the model, two retrospective questions were added to the 1989 survey to increase the information on diffusion. Each farmer was asked the year he or she first used the ridge planting method and the year he or she began farming. This information provided sample estimates of the number of adopters in each year from 1980 to 1989 and the number of farmers engaged in farming in that same year. The adoption percentage was calculated as the ratio of the number of farmers that had adopted ridge planting by year t to the total number of farmers in year t.

The retrospective questions supported the conclusion from the field surveys that rapid adoption of ridge planting had occurred, but there were minor discrepancies between the two diffusion estimates.[3] Hence the logistic curve was fitted using each data set (table 3), and the rate of return to CMR was calculated using each estimated diffusion path.[4]

The final step to calculate the benefits of the CMR program is to estimate k^0_{it}, the level of

[3] Estimates from the field surveys of the percentage of farmers adopting ridge planting in 1981, 1982, 1987, and 1989 are 8, 5, 37, and 33% respectively (table 1). Estimates from the retrospective questions on adoption are 4, 6, 25, and 35% for these same years. The small discrepancy between the two surveys in 1989 is the result of some nonresponse and the fact that the sample for the retrospective questions includes some farmers from the surveys in previous years who were not included in the 1989 field observation sample.

[4] Because no time trend in wheat area could be identified, total wheat area in the valley for years after 1990 is assumed to be the average area for 1956–89.

adoption of the improved practice in the absence of the CMR program. Ridge planting is a new practice for wheat and requires some adaptation of planting equipment; it seems unlikely that this method would have been developed and spread by farmers alone. For insecticide, the high cost of prophylactic treatments might eventually have led to reduced insecticide use. However, the high level of skill required to identify pest and predator populations in relation to climatic conditions and the stage of crop growth makes it unlikely that IPM would have been adopted rapidly without an active IPM program. Hence for both innovations, k_{it}^0 was initially assumed to be zero, but in the case of IPM, sensitivity analysis was used to determine the effects of variation in this assumption.

Costs of Research and Technology Transfer

Expenditures on CMR for wheat are not a conventional accounting category in CEVY financial reports, where expenditures are reported by disciplinary and commodity research programs. Expenditures on wheat CMR were estimated by assuming that the cost share to wheat CMR within each accounting category was equal to the proportion of wheat CMR experiments. A prorated share of administrative and laboratory overhead expenditures, based upon numbers of experiments performed, was also included in the calculation of CMR expenditures on wheat.

The Mexican economic crisis of the 1980s has placed CEVY under severe budgetary pressure. Real research budgets fell by over one-half in the 1980s.[5] Crop management research on wheat suffered most, falling from an average of 14% of total research expenditures prior to 1981 to just 6% in more recent years. In contrast, wheat breeding maintained a relatively constant 11–12% budget share. Administrators apparently judged that crop breeding was a higher priority than CMR.

Annual extension expenditures were approximated by assigning an annual value of P 15,000/ha (about US$ 6) to those producers (over 80%) who reported one or more extension contacts per month.[6] This value was based on the fee charged by private consultants, who are an important source of extension advice in the area. Because some extension advice relates to the choice of wheat varieties 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 average annual cost of extension services for CMR of US$ 350,000 (nearly one billion pesos), which is more than double the average annual expenditure on CMR.

Table 3. Diffusion Model Estimated Using Retrospective Data and Field Observation Data

	Field observations[a]	Retrospective questioning[b]
β	0.324	0.344
	(3.48)	(16.07)
α	−2.69	−3.69
	(4.97)	(30.07)
C	0.70	1.00
R^2	0.86	0.98
n	4	9

Note: Numbers in parentheses are t-ratios.
[a] OLS.
[b] Corrected for autocorrelation.

The Internal Rate of Return to the Research Investment

The internal rate of return to the investment in CMR was calculated under a variety of assumptions about the cost and benefit flows (table 4). The deflated cost and benefit streams under the base assumptions are shown in figure 1. The assumptions used for the time paths of the benefit and cost flows in the base model are the following. Crop management research costs run from 1977 to 1988. We assumed that there would be a two-year lag between the initiation of research and the extension of the innovation, but that extension advice would continue to be necessary to maintain the benefits of the innovations. Farmers were assumed to begin ridge planting in 1981, and benefits and extension costs were (arbitrarily) assumed to continue until 30 years after the beginning of the research effort, following the projections from the estimated logistic equations for diffusion. Pesticide reduc-

[5] Spending on agricultural research in the Yaqui Valley averaged approximately 1% of the value of agricultural production. In terms of human resources, the research station being examined might be characterized as one of the better endowed centers in a relatively large national system. In 1984, 41% of CEVY researchers had MS degrees and 23% had obtained a doctorate.

[6] A value of zero was arbitrarily assigned to those farmers who received less frequent extension contact.

Table 4. Sensitivity of Internal Rate of Return to Model Assumptions

	IRR (%)
Base model	
50% of extension costs assigned to CMR	
100% ceiling for diffusion for planting method[a]	
30% gain in insecticide use efficiency	16
No maintenance research required	
Alternate assumptions	
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
70% diffusion ceiling for planting method[d]	15

[a] Diffusion estimates derived using data from retrospective questions on adoption.
[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] Diffusion estimates derived from field survey data on adoption in 1981, 1982, 1987, and 1989.

tion was estimated to have been 10% in 1987, 20% in 1988, and 30% in all subsequent years up to 2006.

The estimated rate of return to the research and extension investment is 16%. This rate of return falls at the lower end of the range of estimated returns to agricultural research reported in Ruttan (p. 242). However, the rate of return may be lower in this study because we have included extension costs, which are not considered in most other studies. Excluding extension costs, the rate of return is 23%, within the range reported in other studies.

The rate of return was calculated under two assumptions concerning the diffusion of ridge planting. The base scenario uses diffusion estimates based upon retrospective questioning of farmers on the year of adoption for the period up to 1989, and predicted diffusion based upon the logistic equation estimated with these data. The second scenario uses the field observation estimates of adoption for the survey years of

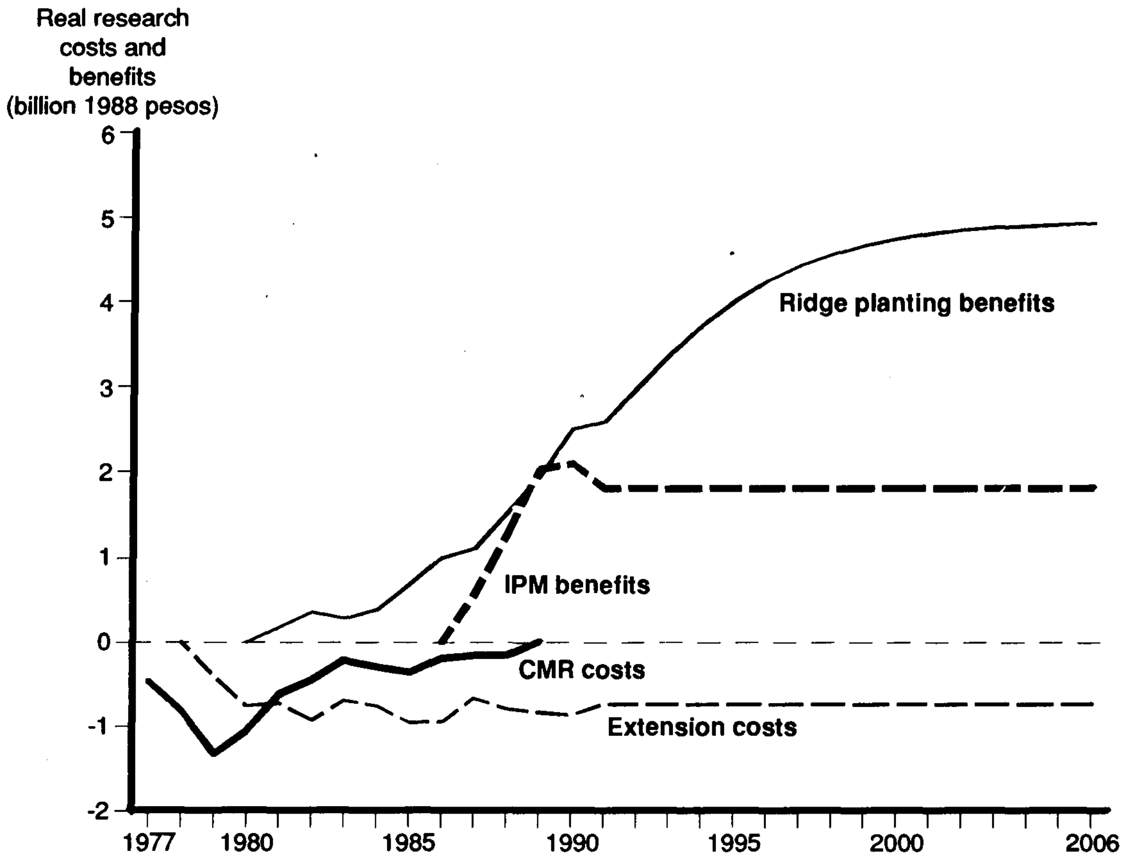

Figure 1. Estimated flows of benefits and costs to CMR on wheat in the Yaqui Valley, Mexico

1981, 1982, 1987, and 1989 and predicted diffusion for all other years, using the logistic equation estimated from the field observation data. The IRR is nearly identical under both assumptions—not surprising, because pre-1989 estimates are similar and discounting substantially reduces benefit flows late in the period. The model is also insensitive to the inclusion of maintenance research costs and the size of the reduction in insecticide use. However, the share of total extension costs allocated to CMR has a noticeable effect on the IRR.

It is important to note that all of the benefits of the CMR program were generated by research on, and subsequent diffusion of, just two out of nine innovations. However, the cost of the total research program has been used in the calculations. Previous studies have estimated only the returns to individual CMR projects. The difference between the *ex post* return to a successful project and the return to a portfolio of projects can be large. Among the individual projects considered in this study, the return to the development of the ridge planting method is estimated to be in the range of 50% and the return to investment in IPM research to be over 100%, compared to 16% for the portfolio of all CMR projects. The fact that a considerable amount of CMR was apparently unproductive argues for more careful monitoring of farmers' acceptance of results of CMR. Such monitoring is already done in many countries to assess the adoption of new varieties developed by plant breeding programs.

Conclusions

This paper has focused on an important but neglected area in the study of returns to research. Although research on crop management accounts for perhaps half of the resources invested in crop research, only a handful of studies have measured returns to CMR, and then only at the project level. The limited number of previous studies results from two problems in estimating returns to CMR: the difficulty of identifying the products of CMR and the problem of unambiguously attributing changes in farmers' crop management to the results of CMR.

A systematic attempt to identify changes in research recommendations was used to distinguish the products of a CMR program and to measure their effects on economic surplus. This approach carefully identifies the products of CMR by monitoring changes in recommendations made to farmers; by monitoring changes in farmers' practices to see if these changes are consistent with the modified recommendations; and then by establishing what proportion of the changes in farmers' practices is a result of CMR versus other sources of supply of improved information and skills. With this information in hand, the calculation of returns to a CMR program follows standard methods, although we deem it necessary to include extension costs in the calculations.

This study supports the hypothesis that the development of improved crop management practices can contribute significantly to increases in agricultural productivity (characterized in post-green revolution agriculture by high input use and yields) through increasing the efficiency of input use. Both successful innovations examined in this paper reduce input use and costs without sacrificing yields. This finding is important because one legacy of the green revolution is that, for many research administrators, policy makers, and aid agencies, technical change in agriculture has become nearly synonymous with developing improved plant varieties and increasing intensification of input use. The findings presented here, and the increasingly important objective of addressing sustainability issues through improved input efficiency, argue strongly that nongenetic or crop management research has an important role to play in the future.

A robust conclusion concerning the magnitude of the return to CMR cannot be based upon the results of a single study. The conclusion that the return to crop breeding research is high has become accepted only after dozens of studies over a 30-year period. Clearly, the return to relevant CMR carried out by competent scientists is potentially very high. Project evaluations by Martínez and Sain, and Norgaard demonstrate that high-payoff CMR projects do exist. In the case examined in this paper, the benefits generated by only two innovations supported the costs of an entire CMR program.

Nonetheless there are examples of CMR that have provided few benefits. This is particularly true for fertilizer response research, which accounts for a large share of CMR in most countries. Despite the thousands of fertilizer experiments that have been conducted, most research systems still make uniform fertilizer recommendations for large heterogeneous crop areas. Furthermore, the rapid increase in fertilizer use in many countries over the past two decades has probably resulted more from breeding varieties responsive to fertilizer, improving the supply of inputs, and providing price incentives through fertilizer subsidies, than from results of research on fertilizer response. Although the CMR program at CEVY has developed more specific fertilizer recommendations, farmers' fertilizer doses depart markedly from the recommended doses and this gap has grown over time.

The rate of return to any research program, however, is a weighted average of the returns to individual projects, so the key question is whether it is more or less difficult for CMR to generate a successful portfolio of projects than for crop breeding research to do so. For a program to generate a favorable rate of return, the "overhead" of low return projects must be offset by high payoff projects. We would argue, for example, that continuous response research on input levels is an overhead expense that could be reduced in many CMR programs. Finally, an important measure for improving the efficiency of investments in CMR is to monitor the evolution of farmers' practices more closely to identify research areas where the CMR program, including associated extension inputs, is not providing payoffs.

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