MILESTONES

in Impact Assessment Research in the CGIAR, 1970-1999

Prabhu L. Pingali

With an annotated bibliography

Matthew P. Feldmann

SPIA **TAC** **CGIAR**

Milestones in Impact Assessment Research in the CGIAR, 1970-1999

Prabhu L. Pingali*

*With an annotated bibliography of impact assessment studies conducted in the CGIAR, 1970-1999, prepared by Matthew P. Feldmann**

Standing Panel on Impact Assessment (SPIA),
Technical Advisory Committee (TAC) of the
Consultative Group on International
Agricultural Research (CGIAR)

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The Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org) is an international association of 58 public and private sector members that supports 16 international Future Harvest centers (www.futureharvest.org) that conduct research with farmers, scientists, and policymakers to alleviate poverty and increase food security while protecting natural resources. The Standing Panel on Impact Assessment (SPIA) of the CGIAR Technical Advisory Committee (TAC) provides information on the impact of past CGIAR outputs with respect to CGIAR goals, complements the *ex post* assessment activities of the Future Harvest centers, and provides feedback to strategic planning and priority setting in the CGIAR. CIMMYT (www.cimmyt.org) , a Future Harvest Center, is a non-profit, scientific research and training organization that works with agricultural research institutions worldwide to improve the profitability, productivity, and sustainability of maize- and wheat-based cropping systems for poor farmers.

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Abstract: This report identifies "milestones" in impact assessment research by the international research centers of the Consultative Group on International Agricultural Research (CGIAR). Milestones are theoretical or methodological research contributions that identify and analyze new areas of impact assessment research and that have been published in refereed publications. The report covers the development of impact assessment research in the CGIAR, charting the progression from assessments of the impact of germplasm adoption and crop management research in the 1970s and 1980s, to formal rate of return and benefit distribution studies in the 1980s, research on spillover and intersectoral impacts in the 1980s and 1990s, and gender and environmental impact assessment research as the 1990s progressed. The role of the CGIAR scientists in this evolution and broadening of scope is documented, as well as the CGIAR's contribution to (and benefits from) impact assessment research in universities and non-CGIAR research centers The report also highlights the role of impact assessment research in producing a picture of solid accomplishments of CGIAR research with respect to poverty, food security, and the environment. The report concludes with comments on future needs for impact assessment research within the CGIAR. An annotated bibliography of CGIAR impact assessment studies follows the report and serves as a useful guide to this significant area of CGIAR research.

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Dedication

This paper is dedicated to Vernon Ruttan, who was the first economist to work for a CGIAR Center (the International Rice Research Institute, 1963-1965). Economists—past and present—in the CGIAR owe him our gratitude for leading the way.

Acknowledgments

Hans Gregersen, the Chairman of the Standing Panel on Impact Assessment (SPIA) of the Technical Advisory Committee (TAC), and Guido Gryseels, the Deputy Executive Secretary of TAC, were instrumental in helping me conceptualize and write this paper. They provided substantive comments on drafts of the paper and provided financial support for its publication. The first draft of this paper was written during a one-week personal retreat at Stanford University in March, 2000. My long discussions with Wally Falcon at that time, and his subsequent comments on various versions of the paper, helped me enormously. Comments, suggestions, and help from Alex McCalla, Robert Herdt, Timothy Reeves, Michael Morris, and several members of the CIMMYT Economics Program are gratefully acknowledged. Comments and criticisms from the participants of the SPIA workshop on impact assessment, held in May 2000 in Rome, helped clarify my thinking and provided useful leads to references that I had previously overlooked. I am also grateful to CIMMYT colleagues Kelly Cassaday, Head of Information Services; Satwant Kaur, CIMMYT Economics Program Editor; and Miguell Mellado, Head of Production, for editing and publishing this review.

Foreword

It is quite widely accepted that the CGIAR has had, over its lifetime, a significant, sustainable impact on poor people by helping to develop the technologies and agricultural management tools that have permitted increased food security and dramatic lowering of the cost of producing the major food crops of the world. This, in turn, has benefited both poor producers and consumers. A recent SPIA study has documented and confirmed this conclusion at the CGIAR-wide level (Evenson and Gollin 2001).

What is not so well known is the significant contributions that CGIAR scientists have made in advancing the theory and methods of impact assessment which have been used to identify and estimate the people-related impacts of agricultural research. For the first time, this "other" role of the CGIAR has been systematically documented through the accompanying study of "milestones" in CGIAR impact assessment research. The author, Dr. Prabhu Pingali, Director of the Economics Program at CIMMYT, has been intimately involved in this work over the past decades and is an appropriate person to document CGIAR contributions. This paper was originally prepared for a May 2000 workshop sponsored by SPIA, "The Future of Impact Assessment in the CGIAR: Needs, Constraints, and Options" (TAC/SPIA, forthcoming).

Dr. Pingali carries out the study in an objective fashion by identifying "milestones" in impact assessment research conducted within the CGIAR centers. Milestones are defined as research contributions that identify and analyze new areas of impact assessment research, whether they be theoretical or methodological. A key characteristic of milestones is that they are quickly followed by other, similar studies within and outside the CGIAR that verify the findings of the milestone research. In all cases, the milestone research is published in refereed publications. Given these defining characteristics of "milestone" research, it is possible to develop an objective picture of the importance of CGIAR contributions in the evolving world of impact assessment research.

The study traces the evolution of this research in the CGIAR, concluding that there is a logical evolution from the relatively narrow focus in the 1970s and 1980s on assessment of impacts of germplasm adoption and crop management research, to formal rate of return and benefit distribution studies starting in the 1980s. The next major broadening in the 1980s was to work on spillover and intersectoral impacts. Finally, in the 1990s the activity has broadened further into gender and environmental impact assessment research.

The role of the CGIAR scientists in this evolution and broadening of scope has been important. In addition to contributions made by CGIAR scientists while working with the CGIAR, it should be noted that many of these researchers have moved on to become leaders in impact assessment research in universities and research centers where they still build on and benefit from their early impact assessment research in the CGIAR. Thus the indirect contributions of the CGIAR are widespread. At the same time, as Dr. Pingali emphasizes, the CGIAR has benefited greatly from the work of others and the interactions that have been possible with scientists in both developing and developed countries.

In tracing the milestones in CGIAR impact assessment research, Dr. Pingali paints a broad yet in-depth picture of how activities within the CGIAR System have contributed to this growing and dynamic field. At the same time, as he points out, the milestone research and use of its methodological results in more routine impact assessments of CGIAR research have produced a picture of solid accomplishments and impacts of CGIAR research with respect to the main goals of the System, which are to have agricultural research results applied in such a way that there are sustainable impacts on poverty, food insecurity, and the environmental resources on which all agricultural production depends. He provides some insights into the road ahead and the gaps that remain to be filled by future generations of CGIAR impact assessment researchers.

SPIA commends Dr. Pingali for this study, one that itself will be a milestone in synthesis of past activity in the CGIAR in the area of impact assessment research.

Hans Gregersen
Chair, Standing Panel on Impact Assessment
Technical Advisory Committee
CGIAR

Milestones in Impact Assessment Research in the CGIAR, 1970-1999

Prabhu L. Pingali

Introduction

The Consultative Group on International Agricultural Research (CGIAR) probably has had greater impact on agricultural production, productivity, and the livelihoods of the rural poor in the world than any other agricultural research organization. This paper does not intend to document the substantial impacts of the CGIAR but rather to dwell on the stock and state of impact assessment research conducted by CGIAR scientists, especially economists. What is not so widely realized is that over the past three decades contributions by CGIAR economists and other scientists to the science of impact assessment have in many cases been groundbreaking, and they have created milestones in the ever-increasing body of technical literature on impact assessment theory and methods. In numerous instances, the CGIAR was the forerunner of a substantial body of academic research on particular themes related to impact assessment.

For the purposes of this paper, a milestone is defined as a research contribution that identified a new area or theme of impact assessment research. It can also include methodological contributions. In all cases, the seminal contributions (milestones) were quickly followed by other studies, both from within and outside the CGIAR, which verified the findings or applied the methodology developed in the study. In all cases, the milestone contributions were published in refereed journal articles, books, or official, peer-reviewed publications of a CGIAR Center (not working papers and other non-refereed documents).

Before proceeding with this review, it is important to be explicit about its unique features and shortcomings. This review documents and highlights the important milestones in impact assessment research that can be attributed to current and past CGIAR economists and social scientists. It covers only research on the impacts of technology and management practices; it does not cover the contributions of CGIAR scientists to impact assessment research related to policy research and policy advice. Owing to the limitations of my own knowledge, the focus has been mainly on milestones related to crop research in the CGIAR. Activities related to such themes as livestock, trees, and capacity strengthening have not received adequate attention. At the same time, it should be pointed out that impact assessment research related to these themes is also much less, and there are few CGIAR milestones in these areas that can be discussed. The need for substantial gap filling, in areas covered and studies cited, is recognized and all suggestions will be appreciated.

Categories of Impact Assessment Research

For the purposes of this paper, CGIAR impact assessment research is divided into six categories:

1. Adoption and farm-level production/productivity/profitability impact of modern varieties;

2. Adoption and impact of technical change in crop management and improved input-use efficiencies;
3. Distribution, equity, and food security impacts, including poverty alleviation;
4. Environmental, ecological, and human health impacts;
5. Intersectoral linkages: agriculture as an engine of growth; and
6. Impacts on the research system through spillover benefits, training, and networks.

Most of the early (1970s and 1980s) impact assessment work in the CGIAR was concentrated in the first two categories. Interest in—and significant contributions to—the remaining categories of research came about only in the late 1980s and 1990s (Figure 1). The broadening agenda of impact research in the CGIAR, especially in the 1990s, reflects to a large extent the broadening research agenda of the CGIAR itself and also the changing public perceptions about the impacts of agricultural modernization and technological change. The impacts research agenda of the 1990s also reflects a desire among CGIAR economists to take on more challenging and difficult-to-measure impacts, such as the environmental and ecological impacts of agricultural intensification and modernization.

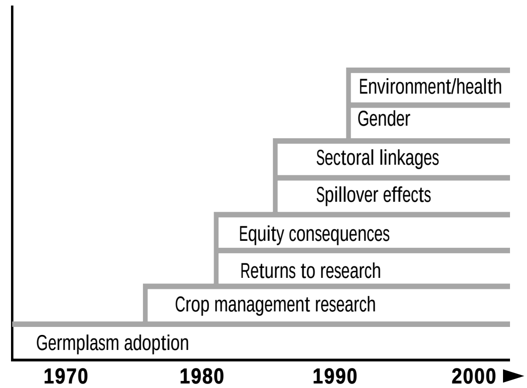


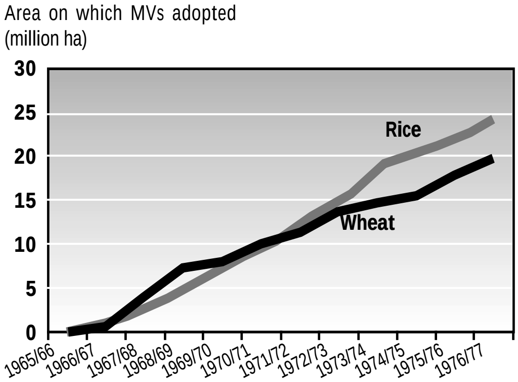
Figure 1. The expanding agenda of impact assessment research.

Adoption and Farm-level Production/Productivity/ Profitability Impact of Modern Varieties

The extent of adoption of modern varieties (MVs) is now well established, at least for the major cereal crops. CGIAR contributions to the content of varieties released by national agricultural research systems (NARSs) are well known on a global basis for rice, wheat, and maize and on at least a regional basis for other CGIAR mandate crops.

Since the early 1970s, substantial work has been done on the extent of adoption and farm-level impact of modern, high-yielding varieties of rice, wheat, and maize. Similar work for other crops, such as cassava, sorghum, millets, and potatoes, followed in the 1980s and beyond. The pioneering studies in assessing the global extent of MV adoption and CGIAR impact were conducted on rice and wheat by Dalrymple in the early to mid-1970s (Dalrymple 1977, 1978, 1986). Dalrymple (1978) provided a quantitative verification of the common perception that the Green Revolution was underway for rice and wheat (Figure 2): "By 1976/77 approximately 30 million hectares of wheat and 25 million hectares of rice in the developing world was planted to high yielding varieties."

Dalrymple's work triggered several in-depth adoption studies, particularly by the International Rice Research Institute (IRRI) and International Maize and Wheat



Source: Dalrymple (1978).

Figure 2. Green Revolution in Asia: The first decade.

Improvement Center (CIMMYT). Herdt and Capule (1983) and Byerlee and Moya (1993) provided detailed assessments of MV adoption for rice and wheat, respectively, in which global, regional, and national adoption figures were differentiated by type of production environment (favorable and unfavorable). Byerlee's work in particular concentrated on identifying the CIMMYT content of wheat varieties released around the world. Other adoption and impact studies that traced CGIAR content in crop releases included Walker and Ryan (1991) for sorghum and millet, Evenson and David (1993) for rice, López-Pereira and Morris (1994) for maize, and Walker and Crissman (1996) for potatoes. The recent effort by SPIA to evaluate the impacts of crop improvement research builds on a long history of CGIAR efforts and expertise in this area (see Evenson and Gollin 2001, who provide detailed adoption and impact information on all CGIAR crops).

The CGIAR Centers have generated substantial empirical evidence on the biophysical and socioeconomic factors that influence the profitability of adopting improved germplasm. IRRI's "consequences of modern rice technologies" studies of the mid-1970s (see IRRI 1978) and CIMMYT's "studies in the adoption of new agricultural technology" (see Winklemann 1976) were the absolute forerunners in adoption case studies. These early efforts identified the impact on farm-level production and income of switching from traditional to modern varieties. The IRRI and CIMMYT studies were done in a standardized case study format across several countries. At CIMMYT, for example, case studies initially started in Mexico and quickly expanded across Asia, Africa, and Latin America. By the early 1980s, about two dozen detailed case studies from around the developing world had documented the farm-level consequences of adopting modern rice, wheat, and maize germplasm. In addition to documenting the positive production and income benefits of MVs, these early adoption studies helped allay fears that the Green Revolution had a bias toward large-scale farmers and an adverse effect on poor farmers and landless laborers.

Aside from documenting the consequences of adopting MVs, CGIAR researchers have made substantial contributions to the literature on the factors constraining the adoption of modern technologies. In his study of rice technology, Herdt (1979) documented the biophysical and socioeconomic factors that explained the "yield gap" in farmers' fields (the yield gap is the difference between the yield that is economically achievable and the yield that is actually obtained). A follow-up publication by Herdt and Mandac (1981) identified the technical and economic constraints to exploiting yields and profits from the adoption of MVs. Herdt's work on constraints to adoption and technology use inspired a whole literature on technical and economic efficiency. CIMMYT's adoption case studies for Latin America, Asia, and Africa also provided detailed information on constraints. Village-level studies (VLS) by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) provided similar information for the semi-arid tropics of India and, later, for West Africa. The VLS dataset that entered the public domain in the mid-1980s spurred a series of doctoral theses (112 at last count), mainly from universities in the United States, whose authors attempted empirical assessments of a large gamut of farmer behavior in the context of technical change.

Other important contributions emerging from case studies of adoption and constraints were detailed assessments of risk attitudes, studies of the variability of farm production, and credit studies. Binswanger's study of risk, done at ICRISAT, was a seminal contribution to the understanding of farmers' attitudes to risk and how those attitudes constrain technology adoption (Binswanger 1980a). Binswanger's work also made significant contributions to the theoretical literature on risk. Anderson and Hazell's (1989) volume on variability in grain yields provided an important synthesis of evidence on production variability in agricultural systems that had recently switched to MVs. The volume covered most CGIAR crops and all continents where the CGIAR Centers worked. *The contention that MVs may be more risky and therefore less attractive to farmers does not seem to have held up in practice.* Stochastic dominance tests of the distribution of returns from improved and traditional varieties typically show new varieties to be dominant. The following studies provided crop-specific results for sorghum and millets (Walker 1989; Witcombe 1989) and rice (Flinn and Garrity 1989; Coffman and Hargrove 1989). More recent studies at CIMMYT (CIMMYT 1991) for wheat and at ICRISAT for millet (Adesina 1988; Shapiro 1990) have reported reduced coefficients of variation for yields over time (Table 1).

Studies estimating the rates of return to CGIAR commodity research investments have consistently shown the investment to be extremely profitable. The returns to investments in high-yielding modern germplasm have been measured in great detail by several CGIAR Centers over the last few decades. These studies found high returns to the CGIAR strategy of germplasm improvement. The very first studies that calculated the returns to research investment were conducted at IRRI for rice research investments in the Philippines (Flores-Moya et al. 1978) and at the International Center for Tropical Agriculture (CIAT) in Colombia (Scobie and Posada 1977, 1978). More detailed evidence on the high rates of return to public-sector investments in agricultural research was provided by the International Service for National Agricultural Research (ISNAR) (Echeverría 1990) and the International Food Policy Research Institute (IFPRI) (Pardey et al. 1992). Table 2 presents a synthesis of early rate of return studies. We ought to recognize, however, that these high rates of return are partly biased by the fact that in general only success stories are incorporated in rate of return studies. For a detailed synthesis of the numerous studies conducted across crops and countries, see Evenson (2001) and Alston et al. (2000). Alston et al. concluded from a review of 289 studies that there was no evidence to support the view that the rate of return to agricultural research and development has declined over time.

Table 1. Expected income and risk of traditional and improved millet technologies in Niger

Author	Location	Traditional	Improved
Adesina (1988)	Maradi	156 (52)	195 (42)
Shapiro (1990)	Libure	446 (52)	628 (56)
	Kouka	301 (49)	409 (39)

Note: Income figures are in US$ (CFA 298/US$ 1). The number in parentheses is the coefficient of variation of income (%).

Table 2. Returns to CGIAR research: first-generation studies

Study	Year	Country (region or institute)	Commodity	Period	Results (rate of return) [a]
Evenson and Flores	1978	Asia	Rice	1950-65	32-39%
		Asia (national)	Rice	1966-75	73-78%
		Asia (international)	Rice	1966-75	74-102%
Flores et al.	1978	Philippines	Rice	1966-75	46-71%
Scobie and Posada	1978	Colombia	Rice	1957-64	79-96%
Martínez and Sain	1983	Panama (IDIAP-Caisan)	Maize (on-farm research)	1979-82	188-332%
Nagy	1983	Pakistan	Maize	1967-81	19%
		Pakistan	Wheat	1967-81	58%
Ambrosi and Cruz	1984	Brazil (EMBRAPA-CNPT)	Wheat	1974-90	59-74%
Monares	1984	Rwanda	Potato seed	1978-85	40%
Salmon	1984	Indonesia	Rice	1965-77	133%
Muchnik	1985	Latin America	Rice	1968-90	17-44%
Unnevehr	1986	Southeast Asia	Rice quality	1983-84	61%
Librero and Perez	1987	Philippines	Maize	1956-83	27-48%
Norton et al.	1987	Peru (INIPA)	Aggregate	1981-2000	17-38%
		Peru (INIPA)	Rice	1981-2000	17-44%
		Peru (INIPA)	Maize	1981-2000	10-31%
		Peru (INIPA)	Wheat	1981-2000	18-36%
		Peru (INIPA)	Potatoes	1981-2000	22-42%
		Peru (INIPA)	Beans	1981-2000	14-24%
Echeverría et al.	1989	Uruguay	Rice	1965-85	52%
Evenson	1988	Paraguay	Crops	1988	75-90%
Norgaard	1988	Africa	Cassava (biological control)	1977-2003	Benefit-cost ratio of 149:1
Evenson and da Cruz	1989	South America (PROCISUR)	Wheat	1979-88	110%
		South America (PROCISUR)	Soybeans	1979-88	179%
		South America (PROCISUR)	Maize	1979-88	191%
Schwartz et al.	1989	Senegal (CRSP)	Cowpeas	1981-87	63%

Source: Echeverría (1990).

a Depending on the study, these are average or marginal rates of return. More than one value means a range of returns depending upon different assumptions or different periods of analysis. Results are rounded. Results of conducting sensitivity tests on various parameters of the models are not presented in this table.

Adoption and Impact of Technical Change in Crop Management and Improved Input-use Efficiencies

Savings in production costs have come about from technical change in crop management and increased input-use efficiencies. Once MVs have been adopted, the next set of technologies to make a significant difference in reducing production costs includes machinery, land management practices (often in association with herbicide use), fertilizer use, integrated pest management, and (most recently) improved water management practices. Although many Green Revolution technologies were developed and extended in package form (e.g., new plant varieties plus recommended fertilizer, pesticide, and herbicide rates, along with water control measures), many components of these technologies were taken up in a piecemeal, often stepwise manner (Byerlee and Hesse de Polanco 1986). The sequence of adoption is determined by factor scarcities and the potential cost savings achieved. Herdt (1987) provided a detailed assessment of the sequential adoption of crop management technologies for rice in the Philippines. Traxler and Byerlee (1992) provided similar evidence on the sequential adoption of crop management technologies for wheat in Sonora, northwestern Mexico.

Machinery Adoption and Use

The early adoption of tractors in the high-potential agricultural areas where the Green Revolution first occurred, particularly in Asia, prompted a series of in-depth studies of the impacts of farm mechanization. Binswanger's study for ICRISAT on the use of tractors in South Asia was a pioneering effort in this area (Binswanger 1978). In the early to mid-1980s, IRRI conducted detailed farm-level studies across several Asian countries on the impact of small-farm mechanization (IRRI 1986). More recent studies at IRRI on the consequences of mechanization have concentrated on harvest and post-harvest operations, including small mills used predominantly by female household members. An important contribution of the mechanization studies was the finding that farm machinery is also adopted sequentially. Machinery is first adopted for power-intensive operations such as tillage and transport, even in labor-abundant societies. Control-intensive operations such as weeding and harvesting, which require knowledge and judgment, are mechanized only as wages rise (Herdt 1983; Binswanger 1984). Consequently, most studies on the impacts of tractor use (for land preparation) found minimal labor displacement even in labor-abundant societies (see Pingali et. al. 1987 for a detailed review of the farm mechanization literature).

Fertilizer Use

Given the importance of fertilizer for realizing the yield potential of MVs, the CGIAR has given surprisingly little attention to assessing the adoption and impact of fertilizer. David's (1976) study of factors that determine fertilizer use at the farm level and David and Barker's (1978) assessment of fertilizer responsiveness are still the best pieces of work in this area. David and Otsuka (1994) provide more recent information on the determinants of farm-level fertilizer use for rice. Despite the history of high fertilizer subsidies in developing countries, relatively little research has been done on the economic incentives and technological options for increasing fertilizer-use efficiency. Few *ex post* impact studies have examined alternatives to chemical fertilizer, including organic fertilizers (e.g., *Azolla*, *Sesbania*), crop rotations, and improved fallows. The limited CGIAR effort to develop and promote these technologies and their limited adoption probably explain the small number of adoption and impact studies conducted on non-chemical fertilizers by the centers. There are two significant exceptions: the work of McIntire et al. (1992) at the International Livestock Center for Africa (ILCA)[1] on crop-livestock integration and of Franzel et al. (1999) at the International Centre for Research in Agroforestry (ICRAF) on improved fallows. McIntire et al. conducted an Africa-wide survey on the extent of crop-livestock integration and its impact on soil fertility management. Franzel et al. have been documenting the extent of adoption of improved fallow systems across East Africa and the consequences for sustaining soil fertility in smallholder production systems.

Integrated Pest Management

Compared to fertilizer use, integrated pest management (IPM) has received far greater attention from the CGIAR's commodity research centers. See Waibel (2000) for a detailed review and assessment of IPM research across the CGIAR Centers. One of the earliest studies on insecticide use was a study on rice (Herdt et al. 1984) conducted as part of a yield constraints study in several countries of Asia between 1973 and 1979. Herdt et al. concluded that the expected returns to rice production are lower for farmers who apply insecticides on a prophylactic basis than for farmers who apply no insecticides at all. This result was validated in on-farm trials by Litsinger (1989) and Waibel (1986).

Three very important studies related to IPM have been conducted in recent years: a study by the International Institute of Tropical Agriculture (IITA) on biological control of cassava mealybug in Africa; an IRRI study of IPM in Asian rice production; and a study by the International Potato Center (CIP) on IPM practices in Andean potato production. IITA's work on cassava mealybug control (Norgaard 1988) was the very first study that attempted to estimate the *ex post* returns to a biological control program. The benefit-cost ratio turned out to be 149:1, triggering an enormous interest in the cassava mealybug program (then under evaluation) and in biological control programs in general. Although Waibel (2000) has cautioned that the returns to crisis research, such as the cassava mealybug program, are generally higher than returns to non-crisis research, such as germplasm improvement, it would be safe to conclude that investments made in mealybug control were extremely worthwhile. IRRI's research on the impact of IPM documented the declining levels of insecticide used on rice and validated earlier findings through farm survey data that natural control (a zero-pesticide strategy) was the most profitable option for farmers, especially when health costs were taken into account (Rola and Pingali 1993; Pingali et al. 1994; Pingali and Roger 1995). The CIP study followed a design similar to that of the IRRI study, but it found a positive productivity benefit to insecticide use and hence a more crucial production versus health trade-off for insecticide applications in Andean potatoes (Crissman et al. 1998).

Although host-plant resistance has always been the cornerstone of any IPM strategy, little work has been done to assess the impact of host-plant resistance on controlling pest losses and reducing yield variability. The exception is the recent work on returns to breeding for rust resistance in wheat at CIMMYT (Smale et al. 1998). Smale et al. not only determined the economic returns to breeding for durable rust resistance but provided a methodology for evaluating the returns to investments in

[1] Now the International Livestock Research Institute (ILRI).

such "maintenance breeding" activities.[2] Maintenance breeding is crucial to the long-term relevance and viability of any breeding program, yet it remains quite invisible in donor portfolios and CGIAR priority setting.

Distribution, Equity, and Food Security Impacts

Widespread adoption of modern seed-fertilizer technology led to a significant shift in the food supply function, contributing to a fall in real food prices. Some of the very early work on the impact of the Green Revolution was directed towards understanding its effects on market prices and food security. The primary effect of agricultural research on the non-farm poor, as well as on the rural poor who are net purchasers of food, is through lower food prices:

> The effect of agricultural research on improving the purchasing power of the poor—both by raising their incomes and by lowering the prices of staple food products—is probably the major source of nutritional gains associated with agricultural research. Only the poor go hungry. Because a relatively high proportion of any income gains made by the poor is spent on food, the income effects of research-induced supply shifts can have major nutritional implications, particularly if those shifts result from technologies aimed at the poorest producers.
>
> Alston et al. (1995:85)

Early efforts to document the impact of technological change and the consequent increase in food supplies on food prices and income distribution were made by Hayami and Herdt (1977) at IRRI, Pinstrup-Andersen (1976) and Scobie and Posada (1978) at CIAT, and Binswanger (1980b) at ICRISAT. Pinstrup-Andersen argued strongly that the primary nutritional impact for the poor came through the increased food supplies generated through technological change.

The profitability of modern farming systems has been maintained despite falling food prices (in real terms), owing to a steady decline in the cost per ton of production. The point that producers have continued to benefit from technological change despite falling output prices has not been emphasized adequately in the literature on research impacts, although empirical evidence does show quite clearly that the cost per ton of production has fallen significantly. Most of the empirical data on changes in unit production costs is on rice. The very first study comparing unit production costs of modern and traditional varieties was done by IRRI (1972) for several Asian locations and found significantly lower costs per ton of production of modern compared to traditional varieties. More recent studies have documented trends in the cost per ton of rice production over time (see Pingali et al. 1997:43 for several Asian locations and Hossain 1998:331 for Bangladesh). Consistently across several Asian countries, unit production costs have tended to decline over time, and over the same period, production costs have generally tended to be lower than output prices. Empirical evidence for the long-term decline in unit costs of production also exists for wheat; see Sidhu and Byerlee (1992) for evidence from the Indian Punjab and numerous publications for evidence from the Yaqui Valley of northwestern Mexico, the starting point for the Green Revolution in wheat.

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2 In crop improvement research, "maintenance breeding" can be defined as any breeding activity that seeks to preserve yield potential and yield stability by maintaining a crop's genetic resistance to evolving biotic stresses such as diseases and pests.

The impact and benefits of technological change have varied by ecological domain, socioeconomic factor, and gender. Many studies have addressed the differential impact of technological change in favorable and unfavorable production environments. David and Otsuka (1994) conducted a study on the differential impact of technological change across rice environments in Asia. They found that although the favorable, high-potential environments gained the most in terms of productivity growth, the less favorable environments benefited as well through technology spillovers and through labor migration to more productive environments. According to David and Otsuka, wage equalization across favorable and unfavorable environments was one of the primary means of redistributing the gains of technological change. Renkow (1993) found similar results for wheat grown in high- and low-potential environments in Pakistan. Byerlee and Moya (1993), in their global assessment of the adoption of wheat MVs, found that over time the adoption of MVs in unfavorable environments caught up to levels of adoption in more favorable environments, particularly when germplasm developed for high-potential environments was further adapted to the more marginal environments.

Income distribution effects across the various socioeconomic groups within a rural community have received some attention in the CGIAR impact literature. In a detailed study of North Arcot District of Tamil Nadu, India, Hazell and Ramaswamy (1991) estimated the distribution of benefits of technological change across landless laborers, tenant farmers, and small and large landowners. David and Otsuka's (1994) study paid particular attention to effects on landless labor and tenant farmers. Their results validated the findings of IRRI's (1978) consequences study, which found that the benefits were shared across the various groups. The early criticism that the Green Revolution had benefited only large-scale farmers was negated by the findings of all of these studies.

In recent years, the differential impact literature has focused on identifying the distribution of benefits between men and women farmers and male- and female-headed households. Paris from IRRI, and Quisumbing et al. from IFPRI, have conducted several studies on the subject. The general finding across crops and continents is that women farmers and female-headed households have gained proportionally less than their male counterparts. Paris (1998) has contended that it is not gender alone that determines whether an individual benefits from technological change, however, but rather the initial social and economic status of the individual. Women from land-owning households who have some control over the land benefited substantially from technological change relative to women from poor, landless households. Quisumbing et al. (1995) concluded from a ten-country study that among the very poor the economic welfare of male- and female-headed households differed very little. Differences emerged only where cultural or institutional factors prevented equal participation in the labor force, as in Bangladesh. For excellent recent reviews of the literature, see Doss (1999) on African maize farming systems and Paris (1998) on rice in Asia.

Environmental, Ecological, and Human Health Impacts

The environmental, ecological, and human health impacts of modern technology have received limited attention from the CGIAR Centers. There are a few significant exceptions to this generalization, including the research on genetic diversity conducted by CIMMYT, on pesticides and health by IRRI and CIP, and on soil erosion in the hillsides of Central America by IFPRI, CIAT, and CIMMYT. A good deal of environmental impact assessment is being done at the CGIAR Centers now, but results have not been published and therefore are not included in this review. The works cited above were all groundbreaking, in terms of the problems they tackled as well as their methodological contributions.

From the very early days of the Green Revolution, the CGIAR has been accused of reducing crop genetic diversity in subsistence farming systems through the widespread promotion of MVs. Smale was one of the first economists in the CGIAR to investigate how intensification and use of MVs affected genetic diversity; she assessed the current stock of diversity in farmers' fields as well as farmers' incentives for conserving diversity (see Smale 1998 for case studies of wheat, maize, and rice). A substantial joint research effort by CIMMYT, IFPRI, and the International Plant Genetic Resources Institute (IPGRI) continues to document changes in genetic diversity in intensive wheat production systems in China, India, and Pakistan.

The impact of intensive and injudicious pesticide use was another issue that dogged the commodity centers of the CGIAR for several decades. While the CGIAR responded by promoting IPM and safer pesticide use, studies that directly addressed the impacts of pesticides were not conducted until the late 1980s. IRRI's study of the impact of pesticides in rice production on human health was a pioneering effort that created renewed interest in IPM research (Rola and Pingali 1993; Antle and Pingali 1994; Pingali et al. 1994; Pingali and Roger 1995). The CIP study on pesticides in potato production was done soon afterward (Crissman et al. 1998). Both the IRRI and CIP studies, conducted in areas of intensive pesticide use, found that adverse health effects could be attributed directly to pesticide use. The similarity in health findings among rice farmers in the Philippines and potato farmers in Ecuador was striking, but as noted previously, the IRRI study found that returns to pesticide use were negative when health effects were explicitly accounted for, whereas the CIP study found continued positive returns even when health costs were considered.

Inter-sectoral Linkages: Agriculture as an Engine of Growth

Studies by CGIAR economists have provided empirical support to the proposition that growth in the agricultural sector has economy-wide effects. One of the earliest studies showing the linkages between the agricultural and non-agricultural sectors was done at the village level by Hayami while at IRRI (Hayami et al. 1978). Hayami provides the best micro-level illustration of the impacts of rapid growth in rice production on land and labor markets and the non-agricultural sector. More recent assessments on the impacts of productivity growth on land and labor markets have been done by Pinstrup-Andersen and Hazell (1985) and by David and Otsuka (1994). Pinstrup-Andersen and Hazell argued that landless laborers did not adequately share in the benefits of the Green Revolution because of depressed wage rates attributable to migrants from other regions. David and Otsuka, on the other hand, found that migrants shared in the benefits of the Green Revolution through increased employment opportunities and wage income. The latter study also documented that rising productivity caused land prices to rise in the high-potential environments where the Green Revolution took off.

An IFPRI study by Hazell and Ramaswamy (1991) showed the development of backward and forward linkages from increased agricultural productivity growth in India. The term "backward linkages" refers to the demand for inputs used in a new production activity, whereas "forward linkages" refers to new processing industries stimulated by the availability of raw materials provided by the new production activity. Delgado et al. (1998), also at IFPRI, found similar evidence of growth being stimulated in the non-agricultural sector by growth in agricultural productivity. The work by researchers at IFPRI has provided strong empirical support for the proposition that agriculture does indeed act as an engine of overall economic growth (Hazell and Haggblade 1993; Fan et al. 1998)

Impacts on the Research System through Spillovers, Training, and Networks

Research on the impacts of the CGIAR on national public-sector research, technology development, and human resource capacity needs to be enhanced substantially.

Research Spillovers

CGIAR economists have made an important contribution to increased research efficiency through their work on technological spillovers. It often takes a long time for knowledge to be developed through research and then adopted. Typically, ten years pass from the initiation of a research project to the dissemination of research results. By borrowing research results (e.g., plant lines or varieties) from other countries, a country can shorten its research time and contribute to increased returns to research investments (Alston et al. 1995).

Several attempts have been made to identify and incorporate such spillovers in research priority setting at the level of individual countries. Brennan (1986), while at CIMMYT, measured the benefits to Australian wheat breeding programs of access to CIMMYT breeding materials. Pardey et al. (1996) measured the benefits to US wheat and rice production from germplasm developed at CIMMYT and IRRI (Table 3). Pardey and Wood (1994) explicitly accounted for cross-border technology spillovers in agricultural research priority setting in Latin America. Morris et al. (1994) conducted a similar assessment for wheat research spillovers from India to Nepal. Maredia and Byerlee (1999) quantified spillover benefits for wheat across agroecological boundaries—in other words, they measured the transferability of wheat varieties developed for one production environment (e.g., an irrigated environment) to another (e.g., a rainfed environment).

Table 3. US benefits and costs (in millions of 1993 US$) from CGIAR wheat and rice research

Benefits and costs	Wheat	Rice
Present value of benefits	13, 653	1,042
Present value of costs	71	63
Benefit-to-cost ratio	190:1	17:1

Source: Pardey et al. (1996).

Training and Networks

The CGIAR has made immense contributions to strengthening research capacity in the national research systems of developing countries, primarily by building human capacity (through training programs) and by improving the exchange of information and technology (through networks). Surprisingly little has been done to measure the impact of CGIAR investments in training and networking. A recent CIMMYT study of the Regional Maize Program in Central America (a maize research network) found high returns to participation in the network, especially for small countries that could not afford a critical mass of crop research and development specialists (Gómez 1999). Substantial work is needed on the economic and social returns to network participation, since this mode of linking researchers in national programs and the CGIAR is expected to continue into the foreseeable future. Measuring the impacts of networks is very difficult, however, because of problems in clearly identifying inputs and outputs and attributing them to the participants in the network. Training is another area in desperate need of a critical impact assessment. Most CGIAR Centers have counted numbers of course participants and assembled anecdotal information on training, but to date no detailed impact assessment has been done. Perhaps the recent SPIA effort to evaluate the impact of CGIAR training will fill this large gap.

Concluding Remarks

Over the past three decades, CGIAR economists have been actively involved in assessing the adoption and impact of MVs and other technologies developed by the CGIAR Centers. Impact assessment at the CGIAR has been recognized for its substantive and methodological contributions by the economics profession as well as by the donor community that invests in the CGIAR Centers. The scope of impacts work done at the centers has expanded from a narrow effort to measure the adoption of MVs to research quantifying a wide array of impacts on production, productivity, equity, human health, and the environment. Numerous high-quality publications in international journals, as well numerous awards received by CGIAR researchers, attest to the high quality of the research conducted at the centers. Even so, several concerns remain to be addressed to enhance and sustain the work that has been done, and also to increase the impact of impact assessment research.

While the scope of impact assessment research in the CGIAR has expanded over time, there continues to be a need (and pressure) to further broaden the agenda of impacts research. Evidence that modern technology has contributed to poverty alleviation is particularly sought after by the donor community. Similarly, studies on the impacts of agricultural modernization on the sustainable management of agricultural ecosystems in general, and biodiversity in particular, are also in demand. CGIAR economists have also begun measuring the impacts of policy research and advocacy, training and human capacity strengthening, and networks for technology generation and exchange. The impact assessment community faces enormous methodological challenges as it gears up to measuring impacts in these areas, but they are also the areas where future milestones can be achieved.

Looking at the record of CGIAR impact assessment research over the past three decades, it is clear that not all centers have been equally engaged in the work. A few centers have had an outstanding record, and many are trying to catch up. What factors distinguish the few successful centers from the rest?

It is likely that the commodity mandate of some centers has made a big difference: centers that achieved technological breakthroughs with enormous impacts also conducted outstanding impact assessment research. Equally important was the value that center leadership placed on building and sustaining economics research capacity. It is perhaps not coincidental that centers with excellent impact assessment credentials also supported an independent economics group with a critical mass of well-trained staff. The experience of the last three decades has shown that there are no shortcuts to sustainable, high-quality performance in impact assessment research.

To maintain professional credibility and ensure high-quality research, it is important that the methods used in impact assessment are the best available and that the work is done in as transparent a manner as possible. The most effective means for centers to sustain the reputations of their impact assessment groups over the long term has been to constantly subject research results to peer review. The long-term publicity value of high-quality impact assessment research cannot be underestimated and ought not be sacrificed for short-term gains.

Although CGIAR economists have a good record in impact assessment research, their ability to communicate their results to a wider audience has been rather poor. Publication in high-quality journals is an essential means of maintaining professional credibility, but the findings of impact research may have their true impact on an audience that does not necessarily obtain its information from professional economics journals, such as taxpayers, development assistance agencies, and philanthropic organizations. Multiple and targeted outputs derived from a set of results would go a long way in helping to achieve the goals of certain audiences while enhancing the mission of the research institution.

It is also very important to recognize that long-term credibility in impact assessment research can be maintained only when the inputs and contributions of all partners are appropriately acknowledged. Many CGIAR technologies are joint products that require significant input from national program partners and increasingly from the private sector. It is sometimes unclear whether the CGIAR can claim exclusive or even partial credit for certain impacts. The nature of the contribution ought to be specified clearly, be it discovery, development, or facilitation.

Finally, there is a fine line between impact assessment research and public awareness activities. As noted above, impact results certainly ought to reach a wider audience, but it must be remembered that the primary function of impacts research is to provide feedback to researchers and to the institution about what is going right and what is going wrong with research and development activities. The opportunity for introspection and mid-course correction is often lost when the balance is tipped too heavily—or prematurely—towards the publicity value of the results.

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Impact Assessment Studies Conducted in the CGIAR, 1970-1999: An Annotated Bibliography

Matthew P. Feldman

Note: *This bibliography covers many, although not all, of the studies cited in this publication. Readers interested in more detailed information on the studies that do not appear in this bibliography are encouraged to consult the authors of those studies or the original publications themselves.*

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Rice farmers from two regions in the Philippines were interviewed to obtain data for an analysis on human health and productivity tradeoffs from limited pesticide use. Through the models utilized in this paper, it is determined that "pesticide use has a negative effect on farmer health, [and] that farmer health has a positive effect on productivity." After examining the health of the sample farmers, Antle and Pingali used regression analysis to estimate the cost of health treatments and the opportunity cost of lost labor from pesticide-related illnesses. These results were then compared with the change in productivity from possible taxes on insecticides and herbicides which would affect incentives and ultimately reduce pesticide use. Antle and Pingali conclude that there are two probable solutions to the problems of pesticide use on human health; either restrict pesticide use through policy measures such as taxes or, alternatively, find different pest management methods that involve the use of safer chemicals or no chemicals at all.

Binswanger, H.P., and J.G. Ryan. 1977. Efficiency and equity issues in *ex ante* allocation of research resources. *Indian Journal of Agricultural Economics* 32(3): 217–31.

This paper discusses the informational components necessary to make effective decisions regarding research resource allocation. Two principal topics, efficiency and equity, are thoroughly examined. Related to efficiency, Binswanger and Ryan present topics including returns to scale, the advantages of private- and public-sector research, and the effect of factor shortage on research endeavors. In discussing equity, the authors compare distribution of technological gains between producers and consumers, laborers and labor owners, and differing regions. It is mentioned that certain technologies are site-specific and thus disproportionately benefit farmers or laborers of particular regions.

Brennan, J.P. 1984. Measuring the contribution of new varieties to increasing wheat yields. *Review of Marketing and Agricultural Economics* 52(3): 175–95.

In determining the consequences of varietal change on production, Brennan explains and evaluates three measures: (1) the index of varietal newness, (2) the proportion of area sown to recent varieties, and (3) the index of varietal improvement. Brennan describes each measure by explaining its function, including the endogenous and exogenous variables, its advantages, and its limitations. An empirical example is evaluated with data from Mitchell Shire in southern New South Wales between 1950 and 1981. The author concludes that one's choice of measure is critical since there is not a high statistical correlation, in general, between the results of each index.

Brennan, J.P. 1986. *Impact of Wheat Varieties from CIMMYT on Australian Wheat Production.* Agricultural Economics Bulletin No. 5. Sydney: Department of Agriculture, New South Wales.

Benefits from CIMMYT-based varieties (CBVs) have been recognized around the world in developed and developing countries. In this analysis, Brennan evaluates the benefits and impact of CBVs of wheat that are commercially cultivated in Australia. He assesses the advantages of CBVs in increasing yields, quality, disease resistance, and their adoption by region, variety, type, class, and grade. Additionally, he conducts an extensive quantitative analysis of the estimated benefits of CBVs by Australian states between 1974 and 1983. Brennan emphasizes the high adoption rates of CIMMYT-based wheat varieties throughout Australia and concludes that the benefits of CBVs in Australia have been profound since the 1960s.

Byerlee, D., and P. Moya. 1993. *Impacts of International Wheat Breeding Research in the Developing World, 1966–90.* Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

Since the Green Revolution, the area planted to modern varieties (MVs) has steadily increased throughout the developing world. Byerlee and Moya conducted an extensive analysis of data from 38 developing countries that included data on the area planted to modern wheat varieties, percentage of adopted varieties from CIMMYT germplasm, and the benefits of CIMMYT research during the post-Green Revolution period of 1977–90. The authors estimate that of the 600 varieties released in the developing world between 1966 and 1990, 75% came directly from CIMMYT crosses or were the result of crosses with CIMMYT parents by national agricultural research systems (NARSs). The new varieties embodied many benefits, including yield gains and disease resistance, which helped CIMMYT to obtain a 54% internal rate of return on its investment. In conclusion, the authors emphasize that additional research will need to focus on improving grain quality and preserving genetic diversity.

Byerlee, D., and E. Hesse de Polanco. 1986. Farmers' stepwise adoption of technological packages: Evidence from the Mexican altiplano. *American Journal of Agricultural Economics* 68(3): 519–27.

The adoption of inputs, either in a stepwise manner or as a package, is dependent upon the relative profitability of each input and not solely on yield increases. Byerlee and Hesse evaluate the adoption of improved barley varieties, fertilizer, and herbicides in two regions in Mexico between 1975 and 1980—a dry region with an annual rainfall of 450–550 mm and a wet region with annual rainfall of 600–700 mm. Their results emphasize that the three inputs studied are not perfect complements in production, even though interaction between inputs does exist, and thus are frequently adopted in a stepwise fashion to minimize risk.

Byerlee, D., and M. Morris. 1993. Research for marginal environments: Are we underinvested? *Food Policy* 18(5): 381–93.

As remnants of the Green Revolution for wheat are seen today through relatively high yields in the developing world, research has begun to focus on the disparity between the benefits of research for irrigated lands and "marginal" environments plagued by poor water control. By simply recognizing the low adoption rates of modern varieties and low yields in marginal environments, people often believe that more investment is needed in this area. As Byerlee and Morris explain, the focus on marginal regions must correspond with the value of the crop from that locale. Background information, including possible reasons for why more resources should be placed on research for marginal areas and reasons for low adoption of modern varieties in marginal environments, is presented along with a model to determine over and underinvestment. By using a congruency model, the authors find that CIMMYT's wheat breeding program and India's research on wheat were not marked by underinvestment in research for marginal regions.

Crissman, C.C., J.M. Antle, and S.M. Capalbo (eds.). 1998. *Economic, Environmental, and Health Tradeoffs in Agriculture: Pesticides and the Sustainability of Andean Potato Production*. Boston: Kluwer Academic Publishers.

In this book, the authors use data from the Carchi Province of Ecuador to quantify the impact of pesticide use on potato production, on the environment, and on human health. The book addresses the demographics of the study region, the methods of assessing environmental and human health impairments, the effect of government policies and exchange rates on pesticide use, and simulation models incorporating the environment, human health, and economic tradeoffs. The authors determine that a ban on pesticide use is not a likely solution; a more probable solution to the problem would be achieved by improving farmer safety measures and application strategies, as well as restricting pesticide use. The models in this book provide a quantitative framework to illustrate the tradeoff between productivity, farmer health, and environmental factors.

Dalrymple, D.G. 1977. Evaluating the impact of international research on wheat and rice production in the developing nations. In T.M. Arndt, D.G. Dalrymple, and V.W. Ruttan (eds.), *Resource Allocation and Productivity in National and International Agricultural Research*. Minneapolis: University of Minnesota.

This early study of the impact of rice and wheat research in the developing world estimates changes in yield and area as well as the role of high-yielding varieties (HYVs) on these changes. It gives background information on the International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI), two initial centers of the Consultative Group on International Agricultural Research (CGIAR). Topics include the direct and indirect effects of HYVs, the gap between yields in research plots and farmers' fields, changes in areas sown to HYVs and crop yield, as well as the effects of innovative technologies on rice and wheat production in developing countries. Two methods are used to determine the impact of new technologies: production function and index number analyses. The implications and limitations of these methods are described prior to estimations of the value of increased output in the early 1970s, principally in Asia. The analysis concludes by emphasizing the importance of impact research in demonstrating the benefits of agricultural research.

Dalrymple, D.G. 1978. *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*. USDA Foreign Agricultural Economics Report No. 95. Washington, D.C.: United States Department of Agriculture (USDA).

During the 12-year period of the Green Revolution (1965/66–1976/77), the area planted to high-yielding varieties (HYVs) of rice and wheat in developing countries greatly increased. This paper presents information on the origins of semidwarf wheat and rice varieties and the development of many HYVs by the International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI). A vast majority of the data regarding area planted to HYVs is a reflection of the area planted to varieties supplied directly from CIMMYT or IRRI or having CIMMYT or IRRI parents. In the case of high-yielding wheat, data on area planted to HYVs in specific countries over all (or portions) of the 12-year period are presented for Asia, the Near East, Africa, and Latin America. In the case of high-yielding rice, data on area planted are available for Asia, the Communist nations of Asia (Lao PDR, People's Republic of China, and Vietnam), the Near East, Africa, and Latin America. In a more aggregate form, the results show that about 19.7 million hectares of HYV wheat and 24.2 million hectares of HYV rice were planted in developing countries in Asia (excluding Communist nations and Taiwan) during 1976-77, making Asia the predominant adopter of HYVs compared to other regions in the developing world. The total area of HYVs of wheat and rice in developing countries (excluding Communist nations, Taiwan, Israel, and South Africa) in 1976-77 was 29.4 million hectares and 25.3 million hectares, respectively.

Dalrymple, D.G. 1986. *Development and Spread of High-Yielding Rice Varieties in Developing Countries*. Washington, D.C.: United States Agency for International Development (USAID).

This publication provides estimates of the area planted to high-yielding rice varieties (HYRVs) from the mid-1960s to the mid-1980s in four geographical regions—South and East Asia, the Near East, Africa, and Latin America, and in 67 developing countries. Dalrymple presents specific time-series data for a few countries in South and East Asia, where HYRVs are widely adopted and data are more often available, and for a few countries in Latin America. Country details related to area planted in selected years and the choice of rice varieties are presented for other countries in the study. The aggregate area planted to HYRVs in developing countries in the four regions, excluding communist nations and Taiwan, was about 39.2 million hectares in 1982/83. When communist nations were included (excluding North Korea), the figure rose to 72.6 million hectares.

David, C.C. 1976. Fertilizer demand in the Asian rice economy. *Food Research Institute Studies* XV(1).

Using aggregate data from 11 Asian rice-growing countries and two farm surveys (one from the Philippines, Indonesia, Thailand, Malaysia, India, and Pakistan, and the other from Laguna, Philippines), David presents a highly quantitative analysis of fertilizer demand functions. Determinants such as rice yield, fertilizer use, fertilizer-rice price ratio, and price elasticities are evaluated. The author studies the dissemination of modern varieties, the quality of the environment and irrigation systems, productivity of fertilizers, and the fertilizer-rice price ratio in explaining varying consumption of fertilizer across countries and within regions.

David, C.C., and R. Barker. 1978. Modern rice varieties and fertilizer consumption. In International Rice Research Institute (ed.), *Economic Consequences of the New Rice Technology*. Los Baños: International Rice Research Institute (IRRI).

As land resources become more scarce and populations continue to grow, the ability of modern rice varieties (MVs) to respond to fertilizer application has become increasingly important. In this quantitative analysis of factors contributing to varying fertilizer consumption, the authors use three datasets: one aggregate set from 12 Asian countries, one farmer survey from six Asian rice-growing countries, and one farmer survey from Laguna, Philippines. Before presenting the results of their analysis, the authors compare MV and traditional variety (TV) responsiveness to fertilizer applications. Then the datasets are used to estimate fertilizer demand functions for Asian rice-growing countries. By using two demand models, the authors derive the relative contributions of the fertilizer-rice price ratio, percentage of area planted to MVs, quality of irrigation, output value, and quality of the environment in explaining the gap between average and high levels of fertilizer consumption. The Asian aggregate data and Laguna farmer data show that MV adoption is a principal factor in explaining the gap between average and high levels of fertilizer use. The fertilizer-rice price ratio also explains a large portion of the differences in fertilizer use in all three datasets.

David, C.C., V.G. Cordova, and K. Otsuka. 1994. Technological change, land reform, and income distribution in the Philippines. In C.C. David and K. Otsuka (eds.), *Modern Rice Technology and Income Distribution in Asia*. Boulder: Lynne Rienner.

Through a highly quantitative analysis of income distribution in the Philippines between favorable and unfavorable cropping environments, the authors evaluate the factors that influence a distinct income differential. In part because of a focus on improving varieties for irrigated and favorable rainfed regions, the productivity gap between regions increases. Regression analysis is utilized to determine the effect of farm size, land tenure, ownership of capital, and technological factors on income. Non-rice income proved to be the most important form of income leading to the income difference between favorable and unfavorable environments. In conclusion, the authors recommended that emphasis be given to increasing human capital and improving research on rice for unfavorable environments to decrease the inequality.

Doss, C.R. 1999. *Twenty-Five Years of Research on Women Farmers in Africa: Lessons and Implications for Agricultural Research Institutions; with an Annotated Bibliography*. CIMMYT Economics Program Paper No. 99-02. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

Even though broad, definitive generalizations cannot be made on why enhanced agricultural innovations are not quickly adopted by female African farmers, this review of a wide array of literature helps to clarify a few potential possibilities. Important questions are raised in this study and potential answers are given for specific regions, but few generalizations for Africa as a whole are presented. Doss emphasizes that lack of access to labor, land, credit, fertilizer, extension, and mechanization are some potential reasons for the lack of use of new maize technologies. Specific cases from regions of Africa help illuminate the diversity in gender issues. The author cautions that the gender situation is continually changing and thus it is important to conduct before and after research on technology adoption. The review is supplemented by a comprehensive annotated bibliography for over 175 references on gender issues and African agriculture.

Echeverría, R.G. 1990. Assessing the impact of agricultural research. In R.G. Echeverría (ed.), *Methods for Diagnosing Research System Constraints and Assessing the Impact of Agricultural Research.* Vol. II: *Assessing the Impact of Agricultural Research*. The Hague: International Service for National Agricultural Research (ISNAR).

Echeverría reviews more than 100 studies estimating rates of return to various crops throughout the developed and developing world. He emphasizes that impact assessment has changed over the last few decades as *ex post* and *ex ante* research have started to move beyond general cost-benefit studies of innovative technology. Current research has begun to focus on spillover effects, distribution of benefits and income, government intervention in agriculture, and the effects of agriculture policy. Echeverría emphasizes that high rates of return for agricultural research signify underinvestment in this area. Following this introduction, the first half of the book focuses on issues such as the consequences of omitting private-sector research, measurement of changes in consumer-producer surplus resulting from quality improvement, and other topics. The second half of the book contains more site-specific case studies addressing research and extension in Peru, and expected returns to pasture improvement in Latin America.

Echeverría, R.G., G. Ferreira, and M. Dabezies. 1991. *Returns to Investment in the Generation and Transfer of Rice Technology in Uruguay: The Case of Rice*. ISNAR Staff Notes 89-50(s). The Hague: International Service for National Agricultural Research (ISNAR).

In this study of rice production in Uruguay between 1965 and 1985, the authors give a historical account of rice in the country before estimating returns from technological change. Even though there are many components that must be accounted for in technological change, this study includes public and private extension and private research. This analysis gives background information including the area, production, and yield of rice for Uruguay from 1931 to 1988, rice exports from 1973 to 1986, countries importing rice from Uruguay, and rice prices between 1981 and 1987. In addition, it is determined that the rate of return to research and extension investment between 1965 and 1985 in Uruguay was 52%, while the benefit-cost ratio was 5.5. The authors also determine that producers captured a large portion of the benefits from research and extension. In conclusion, special emphasis is placed on the concept of spillins, as countries such as Uruguay must be able to investigate, study, and introduce genetic materials and management techniques from other countries to realize high rates of return.

Evenson, R., and C. David. 1993. *Adjustment and Technology: The Case of Rice*. Development Centre Studies. Paris, France: Organisation for Economic Cooperation and Development (OECD).

During a time of market liberalization, privatization, and structural reform in many countries recovering from the financial crises of the 1980s, Evenson and David emphasize that "for inherently public good activities such as rice research the invisible hand of the market is not relevant." They believe that privatization of rice research cannot take the place of public research. In addition to presenting information on past rice consumption and production, the use of genetic resources, distribution of benefits from research, and investment issues, the authors evaluate the effects of "mismanagement" crises from the 1980s on rice research. Following the crises, many governments moved in support of market economies in their efforts to bring about structural reform in the public system. From the available data, it is believed that the "effectiveness" of rice research did not change during the 1980s, but investment in research declined in several countries which have not seen an equal increase during the reform era.

Fan, S., P. Hazell, and S. Thorat. 1998. *Government Spending, Growth, and Poverty: An Analysis of Interlinkages in Rural India*. EPTD Discussion Paper No. 33. Washington, D.C.: International Food Policy Research Institute (IFPRI).

Since the mid-1960s, the number of people living below the poverty line in India has dropped dramatically. For this trend to continue, it is important to evaluate the marginal impact of various government expenditures geared toward achieving a reduction in poverty. The authors use a simultaneous equation model to determine which factors can provide the greatest impact on rural poverty reduction and agricultural productivity growth. Government expenditures studied include the impact of rural roads, agricultural research and development, irrigation, rural electrification, and education. Through estimates of elasticities and numbers of people who would be brought above the poverty line by marginal expenditures, it is determined that additional government expenditure on rural roads would provide the greatest impact on rural poverty. On the other hand, additional expenditure on agriculture research and development would provide the greatest impact on growth in agricultural productivity.

Flinn, J.C., and D.P. Garrity. 1989. Yield stability and modern rice technology. In J.R. Anderson and P.B.R. Hazell (eds.), *Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries*. Baltimore: Johns Hopkins.

This paper looks at the effects of modern rice varieties and related technologies on production stability in Asia. Factors such as irrigation, cropping intensity, area, and pesticide and fertilizer use are analyzed in relation to their effect on production stability. A small case study of Luzon and Mindanao, Philippines, between 1974 and 1978 is used to illustrate some comparisons of the variability of production based on water control and varieties. In addition, the authors explain the importance of protecting diversity and developing effective crop and soil management strategies.

Franzel, S., D. Phiri, and F. Kwesiga. 1999. Assessing the adoption potential of improved fallows in Eastern Zambia. In S. Franzel and S. Scherr (eds.), *Trees and Farmers: Assessing the Adoption Potential of Agroforestry Practices in Africa*.

A five-year improved fallow and maize rotation plan has rapidly become a popular method of cropping in regions of eastern Zambia. The improved fallow technique involves planting trees for two years to help rejuvenate the soil before planting three consecutive years of maize. Franzel, Phiri, and Kwesiga attempt to evaluate the advantages and disadvantages of this system compared to continuous plantings of unfertilized or fertilized maize. They find that over the five-year period, higher returns to land and labor accrued to the improved fallow technique over the unfertilized maize pattern, while the returns to labor were higher for the improved fallow method than the continuous fertilized maize technique. Although under certain conditions the benefit difference between improved fallow and fertilized maize is not stark, it must be emphasized that the relationship in benefits between these two methods depends greatly on the prices of maize and fertilizer. Over the five-year cycle, fertilized maize has the highest overall yield.

Flores-Moya, P., R.E. Evenson, and Y. Hayami. 1978. Social returns to rice research in the Philippines: Domestic benefits and foreign spillover. *Economic Development and Cultural Change* 26(3): 591–607.

In this paper the authors estimate the benefit/cost ratio, internal rates of return, supply and demand elasticities, and spillover effects of rice research in the Philippines. A review of past rice research in the Philippines precedes a description of the methodology used to calculate social returns and the actual calculations. Factors such as price elasticities, research costs at international and national research facilities in the Philippines, and the shift in the rice production function owing to technological innovation are quantified. The estimation section shows that in a closed economy and in the tropical world as a whole, consumers reap the rewards of research, whereas producers fare worse than prior to the research. It is estimated that on average every dollar invested in research in the Philippines translates into a benefit of US$ 4 to the Philippines. Additionally, the benefit/cost ratio is much higher for the tropical world, which illustrates the impact of spillover effects.

Gómez, M.I. 1999. Economic Benefits of Research Cooperation: The Case of the Regional Maize Program for Central America and the Caribbean. Ph.D. thesis, University of Illinois, Urbana-Champaign, Illinois.

Over the past decade, research on impact assessment has begun to include spillover effects. When these effects are not taken into account, estimates of returns to investment and thus financial resource allocation can often be skewed. This award-winning thesis describes and analyzes the sources of the vast benefits of the cooperative breeding program of the Programa Regional de Maíz (PRM, or Regional Maize Program) in Central America and the Caribbean. The author identifies and quantifies spillovers within the region and conducts cost-benefit analyses on public breeding research. Gómez estimates that close to two-thirds of the maize research impact in the study area comes from spillins from outside the region. For the majority of countries in the region, it is more beneficial to invest in the PRM than in national agricultural research. Investment in the PRM opens the door to receiving large spillin benefits from the collaborative international effort, which can capitalize on specialization and returns to scale.

Hayami, Y., and R.W. Herdt. 1977. Market price effects of technological change on income distribution in semisubsistence agriculture. *American Journal of Agricultural Economics* 59(2): 245–56.

Hayami and Herdt emphasize the need for technological innovations to shift the supply function at a faster rate than the shift in the demand function. Through a study of rice variety innovations in the Philippines, the authors quantitatively analyze the income distribution between sectors and within the rural sector using a model they develop. Estimated factors include changes in consumer surplus, producer income, and income distribution between large- and small-scale farmers for both fixed and variable consumption of this semisubsistence crop. In concluding, the authors state that more equality can be reached if innovations shift the supply function faster than the demand function, allowing prices to fall.

Hazell, P.B.R., and C. Ramaswamy. 1991. *The Green Revolution Reconsidered: The Impact of High-Yielding Rice Varieties in South India*. Baltimore: Johns Hopkins.

In this series of papers on the effects of the Green Revolution in rice in North Arcot District of South India, Hazell and Ramaswamy show that the rural poor received both direct and indirect benefits from the technological innovations. Initially the new technology was adopted principally by large-scale farmers, but as time passed smaller farms began adopting high-yielding varieties at similar rates as large-scale farmers. It is estimated that new technology increased rice output, lowered poverty, improved diets, and positively affected the non-farm economy, without leading to broad changes in the number of landless people in adoption regions. Between 1973-74 and 1983-84 "small paddy farmers and landless laborers gained the largest proportional increases in family income." The authors point out that the results of these papers are quite different from those of previous studies, which evaluated the new technology too early in the adoption process. Since many studies were conducted too early, some concluded that the new technology was not scale-neutral, had fostered inequality, and had resulted in disproportionate gains by large-scale farmers.

Herdt, R.W. 1987. A retrospective view of technological and other changes in Philippine rice farming, 1965–1982. *Economic Development and Cultural Change* 35(2): 329–49.

In response to reports stating that innovative technology was principally utilized by large-scale farmers, Herdt uses case studies from central Luzon and Laguna, Philippines, over a 15-year period to show that adoption of modern rice varieties was relatively independent of scale. In Laguna there was no significance in adoption based on farm size. In the Luzon sample, on the other hand, small-scale farmers' adoption of the new technology was slower in the beginning, but at the end of the study period there was no difference in adoption rates between small- and large-scale farmers. Data indicate increases in production from 1966 to 1982, labor use per hectare, double cropping, the use of power tillers, and the use of fertilizer and irrigation. In addition, many farmers switched from sharecropping to leaseholding. Even though there were large increases in yields, farmers' real incomes did not change dramatically because of large increases in production costs. Thus, during the study period, real rice prices were depressed and consumers were the principal beneficiaries of technological change.

Herdt, R.W., and C. Capule. 1983. *Adoption, Spread, and Production Impact of Modern Rice Varieties in Asia*. Los Baños: International Rice Research Institute (IRRI).

In this report, the authors discuss adoption of modern rice varieties (MVs) in South and Southeast Asia, increased production since 1965, and factors correlated with adoption. The authors describe adoption, key players, IRRI's role in the changes, percentage of area planted with MVs, and land categories in 11 countries: Bangladesh, Burma, India, Indonesia, the Republic of Korea, Malaysia, Nepal, Pakistan, the Philippines, Sri Lanka, and Thailand. Modern rice varieties were adopted most rapidly in the Philippines, with 89% of irrigated rice land and 77% of rainfed rice area planted to MVs in 1979-80. In addition, the authors discuss previous regression analyses of variables related to adoption of MVs and fertilizer, including age, schooling, technological knowledge, social class, and family size, and factors that influence variable costs, including farm size, tenure, wealth, fertilizer, and credit availability.

Herdt, R.W., and A.M. Mandac. 1981. Modern technology and economic efficiency of Philippine rice farmers. *Economic Development and Cultural Change* 29(2): 375–99.

With data from Nueva Ecija, Philippines, between 1974 and 1977, Herdt and Mandac attempt to determine factors which lead to the yield gap between potential and realized on-farm rice yields. Even though semidwarf varieties have proven to have relatively high yield capability on experiment stations compared with traditional varieties, these vast benefits have not been entirely realized on the farm. The authors determine that three factors–profit-maximization attitudes, allocative inefficiency, and technical inefficiency–contribute to the yield gap and then quantify the relative effect of each factor on the yield discrepancy. After estimating production functions for each farm and utilizing regression analysis, they conclude that farm size, information, and number of days off the farm are three principal contributors to the economic inefficiency. Herdt and Mandac find that farm size is negatively related with efficiency (i.e., larger farms are less efficient), whereas information and days off the farm are positively related to efficiency.

Herdt, R.W., and T.H. Wickham. 1978. Exploring the gap between potential and actual rice yields: The Philippine case. In International Rice Research Institute (ed.), *Economic Consequences of the New Rice Technology*. Los Baños: International Rice Research Institute (IRRI).

Even though modern rice varieties (MVs) have been exalted as having potential yields of between 6 and 10 t/ha, these lofty expectations have not been realized in farmers' fields: a 1969-70 study in the Philippines found yields of irrigated MVs to be 2.1 t/ha. This paper attempts to discover reasons for the gap in rice yields on experiment stations and in farmers' fields. The authors begin with an analysis of data from an IRRI experiment on rice variety IR20 and estimate the "maximum attainable national average yield" for the Philippines is 4.1 t/ha, taking into account climatic, water, and environmental conditions. The principal explanation for the yield gap is the motivation of farmers to maximize profits more often than yields. The authors explain that farmers must take factors such as risk and diminishing returns into consideration. Of eight input use scenarios, three result in the maximum yield delivering the maximum profit, while five demonstrate that yields below the maximum can result in larger profits. In conclusion, Herdt and Wickham state that water control, solar radiation, season, risk and other economic determinants, yearly variations, and insect, disease, and weed damage are the principal factors accounting for the vast difference between actual and potential yields of modern rice varieties. Thus efforts to diminish the yield gap must focus on these research areas.

Hossain, M. 1998. Rice research, technological progress, and the impact on the rural economy: The Bangladesh case. In P.L. Pingali and M. Hossain (eds.), *Impact of Rice Research.* Proceedings of the International Conference on the Impact of Rice Research, 3–5 Jun 1996, Bangkok, Thailand. Bangkok and Los Baños: Thailand Development Research Institute (TDRI) and International Rice Research Institute (IRRI).

Hossain chronicles agricultural research efforts in Bangladesh and their progress towards reducing poverty within the country. He presents data on research investment, education of researchers, characteristics of modern varieties developed for the country, and dissemination of improved varieties. A comparison of unit costs of rice production between traditional and modern varieties from 1973 to 1993 is presented, which facilitates benefit-cost estimates of research investment in rice. Estimates show that when evaluating cost reductions in rice production the benefit-cost ratio of investment in production and technology transfer is 16.6:1, but when one includes the savings from a decline in food imports, the ratio more than doubles to 36:1. Even though it is frequently argued that benefits of modern varieties accrue disproportionately to large-scale farmers, this study shows benefits to the poorer segments of the population from reduced rice prices and a reduction in poverty within the country.

Islam, Y., and J.L. Garrett. 1997. *IFPRI and the Abolition of the Wheat Flour Ration Shops in Pakistan: A Case-Study on Policymaking and the Use and Impact of Research.* Impact Assessment Discussion Paper No. 1. Outreach Division. Washington, D.C.: International Food Policy Research Institute (IFPRI).

Through research and dissemination of results to government policymakers, IFPRI was able to provide information which eventually led, in part, to the abolishment of Pakistan's wheat ration-shop system. The authors explain IFPRI's five-stage research program and its application to a case study of the ration-shop system in Pakistan. The five stages are: (1) client consultation and research program design, (2) research program implementation, (3) the communication of research results, (4) policymaking, and (5) impact assessment. The case study emphasizes that through close collaboration with key actors inside and outside the government, IFPRI was able to tailor the research to policymakers' interests and provide this information on a continual, timely basis instead of through a final report, which was not published until 1988. The subsequent abolition of this ration-shop system was due, in part, to a wasteful and corrupt system which did not have a strong impact on the poor population.

Litsinger, J.A. 1989. Second generation insect pest problems on high yielding rices. *Tropical Pest Management* 35(3): 235–42.

Recent advances in irrigation, modern variety development, and increased cropping intensity have put pressure on rice yields as farmers now must battle pests that no longer have a natural break in their development cycles. With increased cropping intensity there are no long fallow periods in which the majority of the pests die. The government recommended virulent insecticides to kill pests, but the insecticides also killed natural predators. Because of these insecticides and year-round cropping, pests have become more difficult to control. Litsinger recommends that communities set timetables for the crop season to provide some fallow time and develop integrated pest management (IPM) strategies.

López-Pereira, M.A., and M.L. Morris. 1994. *Impacts of International Maize Breeding Research in the Developing World, 1966–1990.* Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

In this analysis of the adoption of improved maize varieties and hybrids in the developing world between 1966 and 1990, López-Pereira and Morris use data from 45 countries to estimate the area planted to improved varieties and CIMMYT's contribution to the development of those varieties. The authors estimate that in 1990, 24.6 million hectares of land in developing countries, or 43% of the area planted to maize, was planted to improved maize. Since 57% of the area in developing countries planted to maize was planted to unimproved varieties, there is opportunity for further dissemination of improved varieties and hybrids. Of the 24.6 million hectares of improved maize, 13.5 million hectares were planted to improved maize containing CIMMYT germplasm. Between

1966 and 1990, 53% of the 842 maize varieties and hybrids released by public breeding programs in developing countries contained CIMMYT germplasm. In addition to the aggregate analysis, the authors also present a breakdown of countries in sub-Saharan Africa, Asia, North Africa, and Latin America, describing releases and area under local and improved varieties.

Maredia, M.K., and D. Byerlee (eds.). 1999. *The Global Wheat Improvement System: Prospects for Enhancing Efficiency in the Presence of Spillovers*. CIMMYT Research Report No. 5. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

This study of the efficiency of the international wheat improvement system attempts to evaluate the effects of spillovers in developing countries. One principal topic addressed is the decision to breed broadly adapted varieties for vast arrays of environments versus breeding site-specific varieties. By including the effects of research spillovers between programs, both national and international, the authors attempt to eliminate a bias in previous cost-benefit analyses. After evaluating the effects of spillover benefits, the authors conducted an econometric analysis which found that 28 of the 69 research programs studied in developing countries invested too much in wheat improvement research. Many wheat improvement programs in developing countries are too large for their mandate areas and would benefit from investing in programs to screen varieties developed elsewhere. Economic topics, including economies of scale and scope, are addressed as they apply to the comparative advantage of various research programs. Case studies from India and Australia are presented to analyze actual spillover effects and returns to investment.

McIntire, J., D. Bourzat, and P. Pingali. 1992. *Crop-Livestock Interaction in Sub-Saharan Africa*. Washington, D.C.: The World Bank.

In this comprehensive analysis of crop-livestock interactions in sub-Saharan Africa, the authors investigate the potential benefits and limitations of integrating these two agricultural components. To provide a well-rounded study, evidence is obtained from previous research on farming systems as well as recent surveys from 33 African locales. After describing the four climatic regions—humid, subhumid, semiarid, and highlands—the authors provide an overview of crop-livestock interactions, the potential for competition for scare resources, and possible complementary effects. Issues such as animal traction, soil fertility, crop residue, and animal production are integrated into the analysis prior to an overall evaluation of policy recommendations. In conclusion, the authors single out three obstacles to increasing productive crop-livestock interactions: (1) previous trade and governmental policies working against African agriculture, (2) scarcity of information on profitable technology, and (3) a lack of farming methods that are both profitable and relevant to the regions of Africa. It is determined that agricultural growth will not dramatically change even if constraints to crop-livestock integration are alleviated; rather, exogenous technical change should be implemented to help expedite growth.

Morris, M.L., H.J. Dubin, and T. Pokhrel. 1994. Returns to wheat breeding research in Nepal. *Agricultural Economics* 10(3): 269–82.

Because Nepalese research institutes have been established to test and spread improved, imported wheat varieties throughout the country, and because of interaction between Nepalese and Indian farmers, Nepal has achieved high internal rates of return to wheat breeding research during the Green Revolution (1965-90). The authors estimate *ex post* returns to research investment during the Green Revolution and provide an *ex ante* estimate of future returns to wheat breeding research (1990-present). They find that the internal rate of return was 84% during the Green Revolution and predict it to be 49% in the future. In conclusion, they acknowledge that it may not be feasible for smaller countries to conduct extensive breeding research, but as the case of Nepal indicates, it is possible to capitalize on spillover effects from international centers and other countries to achieve a relatively high rate of return.

Moya, T.B., W.C. de la Viña, and S.I. Bhuiyan. 1994. Potential of on-farm reservoir use for increasing productivity of rainfed rice areas: The Philippine case. In S.I. Bhuiyan (ed.), *On-farm Reservoir Systems for Rainfed Ricelands*. Manila: International Rice Research Institute (IRRI).

In this study of on-farm reservoirs (OFR) in Central Luzon, Philippines, the authors determine that constructing an OFR provides good returns on the investment and can be beneficial for farms independent of scale. The paper uses a case study from the 1985 wet season to evaluate the benefits of an OFR. They find that the average rice yield differential between farms with an OFR and rainfed farms is 0.5 t/ha. This difference is compounded when one considers that farmers using an OFR can plant, on average, 40% of their farm area during the dry season and obtain average yields of 2.3 t/ha. Additionally, many farmers use the OFRs to raise fish for home consumption and sale. When certain maintenance and life-span characteristics of an OFR are accounted for, the authors estimate the benefit-cost ratio of OFRs to be 5.1.

Norgaard, R.B. 1988. The biological control of cassava mealybug in Africa. *American Journal of Agricultural Economics* 70(2): 366–71.

Cassava has been a crucial food source in Africa since its introduction 300 years ago. A mealybug was introduced to the continent during the 1970s and caused large crop losses during in the 1980s. Due to the ability of international and national programs to collaborate and capitalize on the biodiversity of South America, a wasp, *Epidinocarsis lopezi*, was found to be a parasite of the cassava mealybug. Because of the low-cost methods of finding, reproducing, and disseminating this parasite, the benefit-cost ratio has been estimated to be 149:1. Empirical evidence shows that measures to control pests through biological means can lead to relatively large benefit-cost ratios.

Palanisami, K., and J.C. Flinn. 1989. Impact of varying water supply on input use and yields of tank-irrigated rice. *Agricultural Water Management* 15(4): 347–59.

Palanisami and Flinn use a simultaneous-equation model to estimate the impact of water supply on rice yields. With data from southern India, the authors estimate the impact of five inputs—tank water, well water, nitrogen, labor, and crop management—on rice yields during years characterized by a water surplus and those marked by a deficit. The model developed in the study allows the authors to numerically explain the factors which cause the difference between low- and high-yielding rice farms. During water-deficit years, the calculated yield difference was 3.74 t/ha, caused principally by a lack of water (60%) and inadequate crop management (34%). During water-surplus years, the calculated yield difference was 1.64 t/ha, caused principally by poor crop management (57%).

Pardey, P.G., J.M. Alston, J.E. Christian, and S. Fan. 1996. *Hidden Harvest: U.S. Benefits from International Research Aid.* Food Policy Report. Washington, D.C.: International Food Policy Research Institute (IFPRI).

Even though the principal focus of the 16 international agricultural research centers of the Consultative Group on International Agricultural Research (CGIAR) is to alleviate hunger in developing countries through increased food production, benefits also accrue to developed countries. This report presents results of a benefit-cost analysis of the US government's research investment in two CGIAR centers, the International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI). These centers conduct research on rice and wheat, important crops for the US. The authors estimate that the benefit-cost ratios of US government financial investment in CIMMYT and IRRI were 190:1 and 17:1, respectively.

Paris, T.R. 1998. The impact of technologies on women in Asian rice farming. In P.L. Pingali and M. Hossain (eds.), *Impact of Rice Research.* Proceedings of the International Conference on the Impact of Rice Research, 3–5 Jun 1996, Bangkok, Thailand. Bangkok and Los Baños: Thailand Development Research Institute (TDRI) and International Rice Research Institute (IRRI).

As farming has become more efficient through mechanization, discussion has heightened regarding the benefits and disadvantages of new technology on women farmers. Paris emphasizes that to study the positive and negative consequences of technology, researchers must pay careful attention to differences in socioeconomic class among women farmers. Such groups include female-headed houses, females in landowning households, and landless female laborers. Through an extensive literature review it is determined that each class of female farmers is affected differently by new technology. This analysis looks at various forms of technology, including modern variety adoption, mechanical reapers, direct vs. hand seeding, rice mills, and herbicides to determine how different classes of female farmers are affected. As long as wages are high, landless female laborers will experience numerous negative consequences of technology because their efforts are replaced by more efficient technological innovations. On the other hand, women from landowning households experience both positive and negative consequences, in which the net result of new technology is still not definitive.

Perrin, R.K., D.L. Winkelmann, E.R. Moscardi, and J.R. Anderson. 1976. *From Agronomic Data to Farmer Recommendations: An Economics Training Manual.* CIMMYT Information Bulletin 27. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

This economics text provides a framework by which agronomists can learn to use economic criteria to evaluate and make farming recommendations. The authors present a step-by-step process of finding a similar set of plots for trials, estimating costs of capital investments, determining benefits and costs along with their variability, and ultimately calculating the expected rate of return. The authors emphasize that factors such as risk and lack of access to capital must be considered in making recommendations to farmers. If the return to the additional investment in a technology is not at least 40%, then it should not be recommended to farmers. Special emphasis is placed on evaluating benefits and costs of potential recommendations at the margin and considering opportunity costs. In concluding, the authors present two examples which help to apply the procedures of evaluating a potential recommendation.

Pingali, P.L., and R.V. Gerpacio. 1997. Living with reduced insecticide use for tropical rice in Asia. *Food Policy* 22(2): 107–18.

During the years following the Green Revolution, insecticide use dramatically increased in Asia. Pingali and Gerpacio estimate that insecticide expenditures in Asia increased from US$ 347 million to almost US$ 1.1 billion between 1980 and 1990. This increase has led researchers to study the returns to high insecticide use and a "zero-insecticide strategy" as well as practices that lie between these two extremes. A study initiated in 1993 in the Philippines showed that areas practicing a zero-insecticide strategy had the highest economic payoff; separate studies have begun to corroborate this finding in other regions of Asia. In determining which method of insect control to use, one must weigh the risks of possible pest infestations from a lack of insecticide against the vast array of health, environmental, and ecological risks of insecticide use. The authors believe that government subsidy programs for insecticides should be removed and replaced by taxes.

Pingali, P.L., C.B. Marquez, and F.G. Palis. 1994. Pesticides and Philippine rice farmer health: A medical and economic analysis. *American Journal of Agricultural Economics* 76(3): 587–92.

In a study of 152 rice farmers in the Philippines, Pingali, Marquez, and Palis evaluate the health effects of pesticide use. Regressions are used to determine the factors—including farmer traits such as alcohol and tobacco consumption, pesticide use, and age—that affect health. The authors estimate the probabilities of having eye, respiratory, gastrointestinal, dermal, and neurological problems under several input decisions. Estimates of health costs range from 1,084 Philippine pesos for no insecticide applications to the opposing extreme of 2,792 pesos for roughly six insecticide applications. When the health impacts of pesticide use are taken into account, it is more profitable for farmers not to apply insecticide. As a result, the authors recommend that there should be regulations to reduce pesticide use and correspondingly reduce the harmful effects on farmer health.

Pinstrup-Andersen, P., N. Ruiz de Londoño, and E. Hoover. 1976. The impact of increasing food supply on human nutrition: Implications for commodity priorities in agricultural research and policy. *American Journal of Agricultural Economics* 58(2): 131–42.

In this paper the authors develop a procedure to evaluate the relative priority that should be given to research on specific commodities to achieve increased calorie and protein intake. They use data gathered from an urban population in Cali, Colombia, between 1969 and 1970. The authors divide the sample into five income categories and then analyze changes in nutritional intake based on a supply increase. They provide estimates of calorie and protein intake, percentage of the supply increase consumed by nutrient-deficient categories, priority rankings for agricultural commodity research based on calorie and protein objectives, and price elasticities of selected food products for each income category. The authors point out that maize is an extremely important means to increase calorie and protein intake because its priority level is in the top five for the tested assumptions of supply elasticity and cost.

Quisumbing, A.R., L. Haddad, and C. Peña. 1995. *Gender and Poverty: New Evidence From 10 Developing Countries.* Food Consumption and Nutrition Division (FCND) Discussion Paper No. 9. Washington, D.C.: International Food Policy Research Institute (IFPRI).

Quisumbing, Haddad, and Peña analyze the relationship between gender and poverty by using the stochastic dominance method. The 10 countries studied are Botswana, Côte d'Ivoire, Ethiopia, Ghana, Madagascar, Rwanda, Bangladesh, Indonesia, Nepal, and Honduras. After explaining the method used to measure gender differences, the authors discuss the difficulties in classifying households into male- and female-headed households. A brief description of stochastic dominance precedes the analysis. The authors find only a few cases in which female-headed households are worse off than male-headed households, including cases from rural Ghana and Bangladesh.

Renkow, M. 1993. Differential technology adoption and income distribution in Pakistan: Implications for research resource allocation. *American Journal of Agricultural Economics* 75(1): 33–43.

Renkow utilizes a multimarket model to test income distribution under technological innovation in Pakistan. The paper begins with an overview of wheat in Pakistan and the multimarket model. For the analysis of income distribution, Renkow divides the sample population into small and large irrigated farms, landless farmers, small and large rainfed farms, and poor and rich urban dwellers. The model is used to identify the principal recipients of technological innovation under various conditions. Renkow concludes that when wheat prices are controlled by the government, net-producing households, which include large, rainfed farms, and small and large irrigated farms, are the primary recipients of economic gains. When the market controls prices, net-consuming households, which include small, rainfed farms, landless farmers, and the urban population, stand to benefit the most from technological innovations.

Rola, A., and P. Pingali. 1993. Pesticides, rice productivity, and health impacts in the Philippines. In P. Faeth (ed.), *Agricultural Policy and Sustainability: Case Studies from India, Chile, the Philippines, and the United States.* Washington, D.C.: World Resources Institute.

In this study, Rola and Pingali estimate the net benefits of four insect control practices in the Philippines when taking farmer health into consideration. The four pest management practices evaluated are: (1) complete protection, (2) economic threshold, (3) natural control, and (4) farmers' practice. Initially, the benefits of each treatment are estimated under several climatic and market conditions. After explaining health consequences of pesticide use and comparing the number of cases of certain illnesses in exposed and unexposed villages, the authors calculate the expected utility of each practice, taking health costs into consideration. When health costs are accounted for, the management practices with the greatest to lowest net benefits are the natural practice, farmers' practice, economic threshold, and complete control. The authors recommend that governments restrict the use of the most hazardous pesticides, thereby creating an incentive to use safer chemicals.

Sain, G.E., and H.J. Barreto. 1996. The adoption of soil conservation technology in El Salvador: Linking productivity and conservation. *Journal of Soil and Water Conservation* 51(4): 313–21.

Combining productivity-enhancing and soil-conserving techniques into one recommendation proved successful in Guaymango, El Salvador. Even though Sain and Barreto give numerous possible reasons why farmers in other parts of El Salvador did not adopt the recommended method of soil conservation when it was proposed 15–20 years ago, they dedicate the majority of the paper to emphasizing reasons why a large proportion of Guaymango farmers did adopt them. The authors explain how the format of the program, which divided farmers into groups and supplied credit only to groups whose members followed the entire recommendation, allowed for the package recommendation to be widely adopted. Empirical evidence shows that the conservation component of the package increased costs in the short run, but this increase was offset by the strong benefits of the productivity component.

Scobie, G.M. 1979. The demand for agricultural research: A Colombian illustration. *American Journal of Agricultural Economics* 61(3): 540–45.

Scobie uses the case of rice in Colombia to explain seemingly contradictory efforts of government investment in agricultural research and national policy to protect the country's manufacturing industry. These policies economically hurt the Colombian rice industry by artificially altering the exchange rate and affecting returns to investment in several sectors. Scobie brings political and economic issues together in discussing funding for research and the distribution of resulting benefits. Between 1957 and 1974, rice output increased fivefold, thus lowering the domestic price and benefiting consumers. Between 1968 and 1974, rice exports were minimal because of an overvalued exchange rate. In 1975, rice prices fell enough to make exporting a viable option. This change will be evident in the distribution of benefits, as producers and foreign consumers reap more rewards from Colombia's agricultural research.

Scobie, G.M., and R.T. Posada. 1978. The impact of technical change on income distribution: The case of rice in Colombia. *American Journal of Agricultural Economics*. 60(1): 85–92.

This study is one of the earliest endeavors to quantify the distribution of benefits of semidwarf rice varieties in Colombia. After a crippling virus affected rice production in 1957, the Colombian Ministry of Agriculture, the Centro Internacional de Agricultura Tropical (CIAT, the International Center for Tropical Agriculture), and the International Rice Research Institute (IRRI) partnered to develop a semidwarf variety resistant to the virus. Instead of studying the rate of return or efficiency of the new varieties, the authors empirically studied the distribution of benefits or equity to producers and consumers as well as to income levels. This pivotal research concluded that households in lower income brackets received the majority of the benefits of the research.

Sidhu, D.S., and D. Byerlee. 1992. *Technical Change and Wheat Productivity in the Indian Punjab in the Post-Green Revolution Period*. CIMMYT Economics Working Paper 92-02. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

Since the Indian Punjab accounts for roughly one-quarter of Indian wheat production, it is important to analyze past, present, and future possibilities of productivity growth. During the Green Revolution, wheat production increased at a rate of 10% per year in the Punjab. Today, though, the increase is 4.8%. What has changed over the past two decades? Is there a possibility of future productivity growth in the double digits? In this paper, Sidhu and Byerlee document trends in input use, real input and output prices, and productivity. They find that while real wheat prices have fallen, so have total production costs. In addition, there has been a shift from using organic manure and animal labor to chemical fertilizers and tractors. In conclusion, the authors explain that even though farmers captured the majority of the economic gains during the Green Revolution, today consumers are receiving a large share of the gains from reduced output prices.

Smale, M. (ed.). 1998. *Farmers, Gene Banks, and Crop Breeding: Economic Analyses of Diversity in Wheat, Maize, and Rice*. Boston: Kluwer Academic Publishers.

By presenting the results of initial economic investigations of genetic diversity in the three major food crops (wheat, maize, and rice) in developing countries, this volume furthers the understanding of the economic context in which crop breeders make use of genetic resources and their diversity. It provides an annotated catalog of the tools used to measure and value genetic diversity. The book also explores fundamental questions related to the value and efficiency of conserving seed *ex situ*, in gene banks. Several chapters analyze farmers' objectives and incentives for conserving crop genetic resources in centers of crop diversity (*in situ*), offering procedures for monitoring, predicting, and developing potential mechanisms to encourage the conservation of crop genetic resources in farmers' fields. In addition, the book explores methodological issues that are important for studying the economics of crop species diversity in farmers' fields, and it examines how diversity is mediated by policies and institutions.

Smale, M., R.P. Singh, K. Sayre, P. Pingali, S. Rajaram, and H.J. Dubin. 1998. Estimating the economic impact of breeding nonspecific resistance to leaf rust in modern bread wheats. *Plant Disease* 82(9): 1055–61.

Using data from the Yaqui Valley in northwestern Mexico from 1970 to 1990, the authors estimate the economic benefit and internal rate of return on the investment in breeding for nonspecific resistance to leaf rust in modern bread wheats. After explaining the importance of maintenance breeding, the authors quantify yield losses that would have occurred if the varieties had not been bred for nonspecific leaf rust resistance. In conducting the analysis, emphasis is placed on the benefits of nonspecific resistance over specific leaf rust resistance. Using costs of the International Maize and Wheat Improvement Center's (CIMMYT) pathology program, and benefits to the Yaqui Valley between 1970 and 1990 of US$ 17 million, the authors estimate rates of return under several assumptions. The internal rate of return on investment is 13% if a ten-year research lag is present and almost 40% if a five-year lag is present.

Traxler, G., and D. Byerlee. 1992. Economic returns to crop management research in a post-Green Revolution setting. *American Journal of Agricultural Economics* 74(3): 573–82.

Despite numerous endeavors to conduct studies of the impact of agricultural research, crop management research (CMR) has not received adequate attention. Traxler and Byerlee emphasize the need to evaluate an entire CMR portfolio instead of individual projects, because the evaluation of returns to individual projects can inflate the benefits. Whereas the benefits of breeding and actual manufacturing of inputs can be quantified relatively easily, the outputs of public sector research on crop management consist largely of information and knowledge, and their impact is much more difficult to evaluate. From a case study of the Yaqui Valley in northwestern Mexico from 1977 to 1988, the authors find that only two of nine practices developed by the CMR program were adopted by farmers based on recommendations of the local research agency. Thus, despite individual project returns of 50% and 100%, the return on the entire CMR portfolio in this study was 16%.

Traxler, G., and D. Byerlee. 1993. A joint-product analysis of the adoption of modern cereal varieties in developing countries. *American Journal of Agricultural Economics* 75(4): 981–89.

Although grain yield is the principal criterion for evaluating the success of cereal varieties, Traxler and Byerlee evaluate the benefits of joint-product profit maximizing in cereal production. Modern varieties (MVs) are semidwarf and therefore have small straw yields. In joint-product profit maximization, the producer evaluates the relative prices of grain and straw in determining the payoff matrix to MVs and traditional varieties (TVs). This paper presents a model for evaluating joint-product profit maximization under several climatic conditions, during different periods (the pre-Green Revolution, Green Revolution, and post-Green Revolution eras), and under varying relative input and output prices. The authors conclude that MV adoption is slowest in areas with low rainfall where the grain yield differential is not as dramatic between TVs and MVs and the price of fodder is relatively higher.

Unnevehr, L.J. 1986. Consumer demand for rice grain quality and returns to research for quality improvement in Southeast Asia. *American Journal of Agricultural Economics* 68(3): 634–41.

As the benefits of the Green Revolution are seen through large supplies of rice, researchers are recognizing the increasing need to invest in quality-improvement research. Unnevehr suggests that previous research on physical-quality improvement will now be followed by research on chemical-quality improvement. The underinvestment in quality-improvement research can be compensated for by a concerted, collaborative effort between international and national research programs. The author uses the "consumer goods characteristics model" developed by Ladd and Suvannunt to estimate implicit prices of specific rice qualities. Rice markets in three countries, Thailand, Indonesia, and the Philippines, are studied to quantify regional estimates of returns to research. Unnevehr concludes that the demand for milling quality is relatively constant between countries, whereas the demand for chemical characteristics can vary dramatically.

von Braun, J., and P.J.R. Webb. 1989. The impact of new crop technology on the agricultural division of labor in a West African setting. *Economic Development and Cultural Change* 37(3): 513–34.

Von Braun and Webb analyze the effect of a centralized-pump irrigation system for 1,500 hectares in central Gambia on gender roles in agriculture. With the implementation of this new technology in 1983, rice, once a "woman's crop," became primarily a "male-controlled crop." This shift principally occurred because as rice yields increase, rice is no longer grown on individual plots by women, but rather on communal lands under the control of men.

It is this division of labor—between individual and communal plots—and technological change that affect gender roles in rice production.

Walker, T.S. 1989. High-yielding varieties and variability in sorghum and pearl millet production in India. In J.R. Anderson and P.B.R. Hazell (eds.), *Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries*. Baltimore: Johns Hopkins.

Sources of production variability have become critical areas of study as researchers try to ascertain why variability around the world has been rising. Walker uses data from 48 sorghum and 40 pearl millet producing regions in India for two 12-year periods, one before the Green Revolution and one after the Green Revolution, to determine factors contributing to production variability. Initially, it is explained that the vast majority of variability is derived from the covariance between regions. Walker uses a weighted least squares regression to determine the effects of high-yielding variety adoption, irrigated area, and variation in rainfall covariance over the two time periods. Higher adoption of both sorghum and pearl millet has increased yield covariance between regions, a higher rainfall covariance has contributed to higher production covariance, and irrigation changes have contributed to higher covariance for sorghum and lower yield covariance for pearl millet.

Walker, T.S., and C.C. Crissman. 1996. *Case Studies of the Economic Impact of CIP-Related Technologies*. Lima, Peru: International Potato Center (CIP).

Recent emphasis has been placed on demonstrating practical applications of new technologies. This collection of nine case studies describes the impact of research from the International Potato Center (CIP). Walker and Crissman have put together a collection of three case studies on varietal, integrated pest management (IPM), and seed system technology. The studies present cost-benefit analyses of adoption in Eastern and Central Africa, China, Peru, Tunisia, the Dominican Republic, Vietnam, and India. Topics include CIP-24 and Canchán-INIAA varieties, potato tuber moth, sweetpotato weevil, and the Andean potato weevil in IPM research, and various seed projects.

Winkelmann, D. 1976. *The Adoption of New Maize Technology in Plan Puebla, Mexico*. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

This study describes the results of a plan to develop, test, and disseminate recommendations to increase maize yields in Mexico. Winkelmann discusses the objectives and organization of the initiative, as well as factors limiting adoption of the recommendations. In general, the recommendation of increased nitrogen, phosphorus, and planting density dramatically increased yields in the test area. The point of contention, though, was the different ways of measuring adoption rates. Even though adoption of the entire recommendation may be relatively low, the percentage of farmers who implemented components of the new technology is much higher. Winkelmann emphasizes that small-scale farmers will modify their farming practices in anticipation of higher profits, but only to the extent to which they can bear the additional risk. Since implementing the entire recommendation requires numerous increases in inputs, to reduce risks many farmers settle for using a level of inputs intermediate between their original method and the recommendation. The author explains that the rate of return to investment in "intermediate" input research will be higher than intensive input research.

Thus collaborative efforts of research and extension institutions in making and disseminating recommendations have been much more beneficial for farmers than estimates of the adoption of the entire recommendation would illustrate.

Witcombe, J.R. 1989. Variability in the yield of pearl millet varieties and hybrids in India and Pakistan. In J.R. Anderson and P.B.R. Hazell (eds.), *Variability in Grain Yields: Implications for Agricultural Research and Policy in Developing Countries*. Baltimore: Johns Hopkins.

Witcombe uses data on varieties and hybrids in India and Pakistan from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to determine the comparative stability and yields of varieties and hybrids. Individual data are compared with population aggregates for low-, average-, and high-yielding environments through a regression analysis. It is determined that hybrids have higher yields, but varieties are more stable. Mean variance and stochastic dominance analyses are conducted to determine the tradeoff between stability and variance in choosing suitable varieties or hybrids. Mean variance analysis revealed that for all environments studied the variety or hybrid to be chosen was the highest yielding of the options. The stochastic dominance method showed hybrids to be better than varieties for low-yielding environments and over most yield values.

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