Consultative Group on
International Agricultural Research

The Impact of the International Agricultural Research Centers: Measurement, Quantification, and Interpretation

M. P. Collinson and E. Tollens

ISSUES IN AGRICULTURE 6

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About the CGIAR

The Consultative Group on International Agricultural Research (CGIAR) is an informal association of 42 public and private sector donors that supports a network of 17 international agricultural research centers. The Group was established in 1971.

The World Bank, the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Development Programme (UNDP) are cosponsors of the CGIAR. The Chairman of the Group is a senior official of the World Bank which provides the CGIAR system with a Secretariat in Washington DC. The CGIAR is assisted by a Technical Advisory Committee, with a Secretariat at FAO, Rome.

Japan, the United States, and Canada are the leading donor countries, followed closely by several European countries. Developing country members of the CGIAR are China, Brazil, India, Indonesia, Mexico, Nigeria, the Philippines, and the Republic of Korea. The total annual CGIAR budget is some $US300 million.

International centers supported by the CGIAR are part of a global agricultural research system. The CGIAR functions as a guarantor to developing countries, ensuring that international scientific capacity is brought to bear on the problems of the world's disadvantaged peoples.

Food productivity in developing countries has increased through the combined efforts of CGIAR centers and their partners in developing countries. The same efforts have brought about a range of other benefits, such as reduced prices of food, better food distribution systems, better nutrition, more rational policies, and stronger institutions. CGIAR centers have trained over 45,000 agricultural scientists from developing countries over the past 20 years. Many of them form the nucleus of and provide leadership to national agricultural research systems in their own countries.

Programs carried out by international centers in the CGIAR system fall into six broad categories: Productivity Research, Management of Natural Resources, Improving the Policy Environment, Institution Building, Germplasm Conservation, and Building Linkages.

Contents

Acronyms and Abbreviations Used in This Paper

CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CIIFAD	Cornell International Institute for Food, Agriculture, and Development
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
CIP	Centro Internacional de la Papa
IARC	International Agricultural Research Center
ICARDA	International Center for Agricultural Research in the Dry Areas
ICLARM	International Center for Living Aquatic Resources Management
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IIMI	International Irrigation Management Institute
IITA	International Institute of Tropical Agriculture
ILRAD	International Laboratory for Research on Animal Diseases
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
NARS	National Agricultural Research Systems
R & D	Research and Development
TAC	Technical Advisory Committee (of the CGIAR)
USAID	United States Agency for International Development

The Impact of the International Agricultural Research Centers: Measurement, Quantification, and Interpretation*

M. P. Collinson[1] and E. Tollens[2]

Introduction

The mission of the Consultative Group on International Agricultural Research (CGIAR), with its seventeen international agricultural research centers, is to improve the welfare of poor people in developing countries in ways that also improve the future productive capacity of their natural resources while protecting the quality of our wider environment. Impact studies help us to understand how technology influences agricultural production and the welfare of agricultural producers and consumers. This information, in turn, can be used to improve the efficiency of resource allocation for research at the international agricultural research centers (IARCs). Many practical obstacles must be overcome, however, before such studies can fulfill these roles.

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Impact studies have another benefit. Recent reductions in funding for international agricultural research have created new pressures on the centers to demonstrate the impact of their results. Evidence of success, provided by impact studies, helps donor representatives defend CGIAR funding in their domestic budget process. In a time of recession, when burgeoning environmental problems and the breakup of the Soviet Union bring new demands on aid, donors need stronger and clearer evidence of the value of their investments in the CGIAR.

History of Impact Assessment in the CGIAR

In 1979, eight years after its founding, the CGIAR sponsored a review of impact assessment methods and results (Scobie 1979). Scobie found that the high-yield varieties introduced in the mid-1960s benefited mainly low-income consumer groups. He also concluded, however, that they were not an effective means to redistribute incomes among rural groups in which productive assets are not equitably distributed. He further concluded that international investments in agricultural research could be expanded significantly and maintain an attractive economic rate of return. The literature on impact assessments that has accumulated since then supports his conclusion (Evenson 1992).

Before 1985, impact assessments in the CGIAR system were dominated by studies on the short-strawed rice and wheats developed by the International Rice Research Institute (IRRI) and Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), part of the vast body of literature on the "green revolution." Using national-level statistics, the United States Agency for International Development (USAID) documented the development and global spread of high-yield varieties of rice and wheat. Such publications began in 1969 with data from the 1965–66 crop year and continued through 1986 (Dalrymple 1986a, 1986b). These USAID-supported studies were later extended to hybrid maize (Timothy, Harvey, and Dowswell 1988). CIMMYT has recently updated the data for maize and wheat (CIMMYT 1992), and updated figures for rice and wheat show the extensive impact of the short-strawed materials.

Today the developing countries produce some 460 million tons of paddy rice annually from more than 140 million hectares, two-thirds (67 percent) of which is planted with seeds based on IRRI's semidwarf materials. Asia produces 91 percent of this total, and rice provides between 35 and 60 percent of household calories for its 2.7 billion people. Similarly, the developing countries grow some 226 million tons of wheat from 100 million hectares, the seed for more than 60 percent of which is based on CIMMYT semidwarf material.

The benefits of such advances in research continue to multiply long after the initial breakthrough. During the two decades of the 1970s and 1980s, the rice yield in eleven green revolution countries in Asia increased by 63 percent, from 2.03 tons per hectare at the beginning of the 1970s to 3.31 tons per hectare by the end of the 1980s. In the 1980s, wheat yields in developing countries increased by 37 percent, from an average of 1.64 tons per hectare to 2.24 tons per hectare. Four dimensions of the diffusion process for research and technology sustain the flow of benefits:

- Farmers using the new technology get higher yields year after year.
- Further adaptations continue to raise yield ceilings.
- Adaptations extend the technology to farmers growing the crop under different soil and water conditions.

- Adaptations extend the crop to areas previously unsuited to it, creating a new cropping opportunity for farmers working there.

Studies by IRRI have shown that poor urban and rural consumers have benefited from the reduction in the real price of rice caused by higher production. Benefits have spread beyond the irrigated areas. As a result, labor demand in new areas has brought immigration of labor, thereby helping to equalize wage rates across environments (David and Otsuka 1991).

During the period 1984–86, the CGIAR donors funded a major study of IARC impact (Anderson, Herdt, and Scobie 1988). It was supported by twenty-six monographs, including case studies (mostly qualitative) of IARC impacts on individual countries, three regional studies, and other studies on topics of special importance to the donors. A parallel study on the impact of CGIAR training in developing countries was also published by the CGIAR Technical Advisory Committee (TAC) (TAC 1986).

These studies will not be repeated. In the future, the main responsibility for impact assessment will rest with the centers themselves. Most IARCs, however, are not organized for systematic assessment. Self-selecting successes often become the focus for ad hoc studies; cases of negative returns to research investments are downplayed or obscured (Anderson and Herdt 1990). Some CGIAR centers have revised their impact assessment needs, responding to the pressures of five-year external reviews, growing constraints on funding, and the adoption of more formal management processes in a search for greater efficiency. For example, both the International Center for Agricultural Research in the Dry Areas (ICARDA) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) recently recruited agricultural economists to study impact assessment.

Impact assessment continues to pose major resource allocation dilemmas for individual centers and for the CGIAR system as a whole. Full-blown impact assessment of **all** its research products, in collaboration with its diversity of clients, may require a doubling of the **total** CGIAR budget.

The Research and Development Process and IARCs

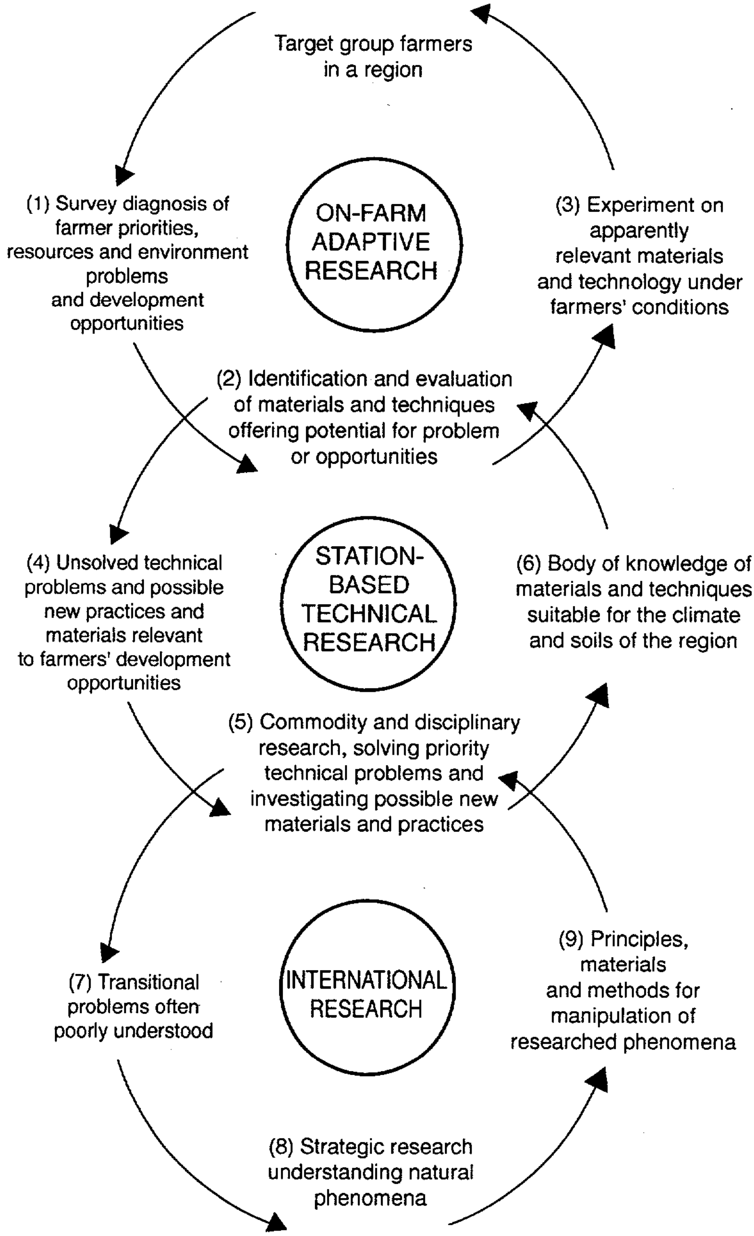
Three levels of activity characterize agricultural research:

- **strategic research**, which is mission focused, seeking to understand those natural and human processes identified as important to the solution of a specified problem;
- **applied research**, which uses existing knowledge to identify approaches and develop prototype technologies to solve problems of widespread importance; and
- **adaptive research**, which aims to articulate farmers' problems, identify appropriate approaches to solution and relevant prototype technologies, and fit these to the particular circumstances of a specific group of farmers.

Another category of research adds to the body of knowledge available to be used, when relevant, in the design of prototype solutions. *Basic research*, often termed "blue sky" research, has no specific problem focus and is not found in the CGIAR.

Figure 1 shows a research paradigm that links these three levels and follows the "farmer back to farmer" configuration. In this model, farmers' problems are identified in the diagnostic stage of the *adaptive research cycle*, ideally by using methods that involve the farmers themselves. Many of these problems can be

Figure 1
An idealized research paradigm (adapted from Collinson, 1982)



solved within a two- to five-year research cycle by adapting technologies that are available from previous formal research or from the experiences of other groups of farmers.

Some problems need new options and prototypes. If they are important to enough people, they find a place in the *applied research* agenda at a national or regional level. Problems whose underlying processes are poorly understood also find priority in the *strategic research* agenda—again, if the problems are important to enough people. At the strategic level, many such problems are relevant to a number of countries and are researched most cost effectively at the regional or international level. These cycles of applied and strategic research will often occupy a ten-year period.

Perhaps the greatest challenge facing the agricultural research community is to build the capacity to operate this research paradigm effectively, in partnership with resource-poor farmers in developing countries.

In practice, these three levels of research do not follow as neat a sequence as Figure 1 suggests. Existing knowledge often can offer some solution. Yet it is frequently clear to researchers that better solutions are possible. Choices among options, rather than one final answer, are increasingly important. The more options that are available, the greater the chance that one will fit the circumstances of any given farming system, and that farmers will readily adapt it to their needs.

Supplying nitrogen to plants is an example. It can be done in many ways: by moving to new land; rotating with green manures; pumping nutrients with leguminous trees; adding compost or organic animal manure; adding inorganic nitrogen out of the bag; and, for some types of plants, fixing nitrogen from the atmosphere. If nitrogen fixation ever can be introduced to other plant types, it will be a major research breakthrough. This effort has already spanned decades but is still pursued as another option, perhaps a superior one, for farmers.

The Development Process

Once appropriate technology is available, other research and development (R & D) sectors need to mobilize its diffusion. It takes time for innovations to spread across target communities, through farmer-to-farmer contact or even an efficient extension service. Farmers themselves will usually experiment on small parts of their fields until convinced of a novel technology's value to them. Making new methods accessible to farmers may sometimes require making credit available so they can afford the purchase. This demands effective enabling institutions and innovative rural banks. Adoption by 80 percent of farmers is often assumed as a ceiling, and it may take a decade to achieve this degree of acceptance. Thus, when new knowledge is needed from strategic research, a twenty-year period is not unusual from the initiation of research to develop options to full benefits of results by farmers.

Many factors inhibit performance in the other R & D sectors, and IARCs sometimes invest in solutions to such inhibitions when it seems important to their research interests. Where the market niches are too small to attract commercial seed producers, for example, Centro Internacional de Agricultura Tropical (CIAT) has had success promoting skilled local farmers as bean seed suppliers to their communities. Vegetative propagation at Centro Internacional de la Papa (CIP) has helped promote local production of improved materials with potatoes, and at the International Institute of Tropical Agriculture (IITA), efforts to use cassava seed for propagation also aim to reduce bottlenecks on the spread of improved cassavas.

For roots and tubers that are usually propagated vegetatively, low multiplication rates make diffusion of

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*All dollar amounts are U.S. dollars.

new plant material particularly slow. Thai scientists selected a CIAT-developed cassava clone, CM 407-7. After several years of testing, it was released as Rayong 3 in northern Thailand in 1984. Innovative farmers were supplied with 600 stakes each and gave 80 percent of harvested stakes to neighbors. The area for stake multiplication was only 16 hectares in 1986. Even though it is estimated that some 70,000 hectares were planted with the new material in 1990, this is still only 4 to 5 percent of the cassava area in Thailand. Adopting farmers get 10 to 15 percent more revenue based on a 5 percent starch premium and in 1990 earned an estimated $3.8 to $4.6 million[301] in extra income. In the long run, Thai cassava will become more competitive in the European market from this kind of innovation (Henry 1991).

Extra production from such innovations may create surpluses where markets are limited. Research can create new market opportunities. Integrated cassava-drying projects in Latin America have been promoted and supported by CIAT and other R & D institutions. From a beginning in 1982 with a single factory for dried cassava chips for animal feed in Colombia, this industry grew to 153 factories in five countries by 1990. Product differentiation — adding dried cassava for animal feed to a market exclusively for fresh cassava for human consumption —created a wider cassava market with more stable prices, thereby stimulating the adoption of dried cassava processing technology.

In Colombia, introduction of improved production technology has been integrated with the cassava-drying plants in the expectation that a more stable market would encourage farmers to increase and intensify their production. Between 1982 and 1990, the proportion of cultivated land devoted to cassava quadrupled among producers in the Cordoba area, and areas of fallow and yams were reduced. The value added to small farmers' incomes from dried cassava production in 1990 was estimated to be $6.6 million, with $1.4 million to local processors; reduced imports of sorghum accumulated savings of $6.0 million of foreign currency by 1990. In Colombia, processing each 1,000 metric tons of dried cassava is estimated to generate 185 person-years of direct labor and 37 person-years of indirect labor (Henry 1991).

Although, as these examples show, centers have intervened in the wider sectors of R & D, many bilateral and multilateral development agencies are active in these sectors. It is clear that the CGIAR, with a budget representing 6 to 7 percent of total developing country agricultural research budgets, has a real comparative advantage only in a limited sector of the sequence. Because the centers' global and regional mandates are for strategic and some applied research, many of the results are intermediate products, to be shaped by further applied and adaptive research to the circumstances of the markets formed by diverse groups of farmers within each country. National agricultural research systems (NARS) have a clear advantage in this applied and adaptive research; at the same time, improved contacts between NARS and farmers better inform the research agenda for IARCs.

Implications for CGIAR Impact

This role in providing many countries with unfinished intermediate products has two key implications for the assessment of IARC impact. First, NARS form a geographically widespread and diverse set of clients. CIMMYT, perhaps the most global of the centers, interacts with up to 100 countries every year. Second, IARCs are highly dependent on the performance of other institutions for successful impact in farmers' fields: on the extension services, on available infrastructure, on market access for both products and for inputs, on policies and, most immediately, on NARS.

The stronger NARS benefit most from CGIAR intermediate products (Anderson, Herdt, and Scobie 1988). Weak NARS are unable to adapt IARC products and unable to feed back information to help formulate a relevant international research agenda. The CGIAR acknowledges that practice falls far short of the R & D sequence idealized in Figure 1; its mandate includes building national capacity to organize and operate an effective research process. Some 20 percent of CGIAR resources are invested in capacity building with NARS. This role involves CGIAR scientists in training, development of methodology, and collaborative research with national scientists, including adaptive research when the aim is a better interaction with farmers. In Africa in particular, IARCs are drawn into applied research and adaptive research, because NARS of some countries have little capacity for these activities. Yet the real comparative advantage of an international effort remains in strategic research relevant to the problems of many countries. The fact that IARCs play a role only in a narrow sector of the total R & D sequence is often overlooked by donors eager for evidence of impact in farmers' fields.

A Conceptual Framework for Impact Assessment

The CGIAR centers have two broad categories of impact. They have direct impact on production, consumption, and human welfare. They also have indirect impact on the research capabilities of NARS and universities in developing countries, and on the general understanding of nature, enlarging the scientific stock of knowledge. Although CGIAR centers have a large effect on building scientific capacity in universities, this is an often neglected aspect of their work (Wilson 1989).

The framework in Figure 2 illustrates the diversity of products from IARCs and the complexity of the chain of repercussions resulting from farmers' adoption of new technologies. Some indicators listed merely record implementation; others quantify its effects.

The Research Cycle and Feedback

The conceptual framework shown in Figure 2 is relevant to both planning the allocation of research resources and the subsequent ex-post evaluation of the impact of research products. The current drop in CGIAR funding has increased the need to choose among research initiatives and to explain those choices when stakeholders, many NARS, and many donors seek center expertise to address their priority problems. As a result, IARCs have growing interest in planning resource allocation.

Setting priorities involves comparing the benefits expected from alternative research initiatives with their estimated costs and the probability of success. One way to measure potential benefits is to estimate current losses caused by the various problems under consideration. Several IARCs, including CIP, ICRISAT, and the International Center for Living Aquatic Resources Management (ICLARM), have made such calculations in preparing new 1994–98 five-year budgets. CIP has recorded and published its process of priority setting (Collion and Gregory 1993).

Solving a research problem is often a continuing process. New knowledge from strategic research allows more options and more effective technologies. The adoption of a succession of improvements gradually reduces the available benefits identified in the initial assessment. Although the greater understanding derived from continued strategic research will usually yield additional benefits, at some point the resources involved—the scientists and funds—would bring greater benefits if they were applied to another problem. This

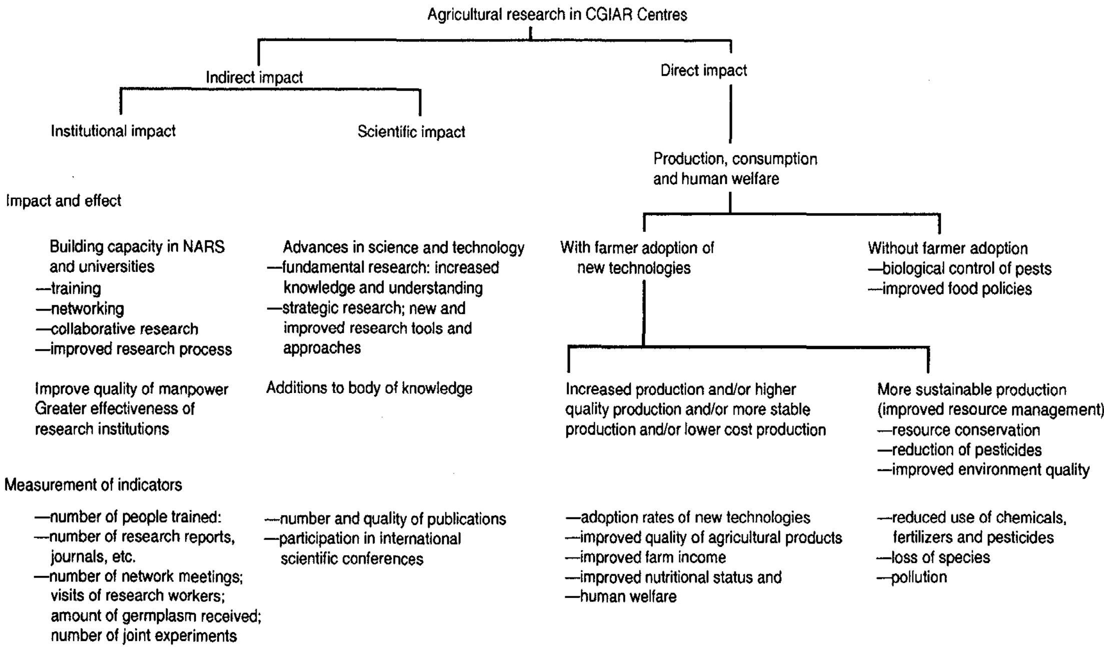

Figure 2
A conceptual framework for impact assessment.

is the issue of the costs and benefits of more information. A key role for research managers is to identify when to switch resources to new problems.

Maintenance research is an exception to this idea of a reducing benefit pile. Continuing efforts are needed to control expected mutations of disease vectors by identifying new sources of resistance. With rice, for example, the fight to control the brown planthopper has been essential to the protection of previous yield gains, particularly in Indonesia. The hopper had always been present as a rice pest, but the denser plant canopy of the semidwarf varieties provided a moist, shady environment that favored it. IRRI collaborated with governments to introduce resistant varieties, the first of which were quickly overwhelmed by a second biotype of the hopper. A second round of new materials remains resistant but will probably provide only temporary respite. If such maintenance research stops, the risk of a food crisis increases.

CIMMYT has estimated that 50 percent of its wheat research has been devoted to keeping ahead of mutating pathogens. Genetic studies at the center have recently identified the basis of a durable form of resistance to leaf rust, one of the three major rust diseases of wheat, an achievement recently confirmed after several years of testing by the U.S. Department of Agriculture (USDA) (Ingersoll 1992). Again, a rough assessment is helpful in allowing stakeholders to judge CIMMYT's achievement. The yield losses that can be avoided if all new wheat materials incorporate this trait should conservatively total 1 percent of the annual crop value, on the order of $135 million each year to producers and consumers in developing countries. CIMMYT will save on the costs of maintenance research, thereby releasing resources to address other problems.

A yield loss assessment helps identify the potential benefits from strategic research programs that bring new understanding as the basis for new options to solve a problem of broad scope. Centers can use such assessment of the numbers of farmers likely to benefit and the estimated level of benefit for each farm to inform, and even excite, their donors, as demonstrated by the following examples.

Nonchemical control of the Mexican bean weevil, a pest of the stored bean crop in Latin America and Africa, has been achieved by adding natural resistance to commercial varieties. Over time, CIAT's work to incorporate the arcelin gene from a wild bean species into varieties grown by farmers will save producers hundreds of millions of dollars and will also protect the environment by offering an alternative to pesticides.

The International Laboratory for Research on Animal Diseases (ILRAD), a strategic research laboratory that has worked for fifteen years to control theileriosis and trypanosomiasis in cattle, is developing bioeconomic models to value the losses from these diseases. Recent tests of the models have estimated annual losses from trypanosomiasis in Zimbabwe at $6.2 million. Further refined, these models will be used to estimate continent-wide losses from the disease and to assess the economics of alternative control options.

As outlined earlier, the full research cycle, from specification of the problem to full farmers' adoption of technical solutions, may occupy a twenty-year period—too long for the redesign or adjustment of ongoing programs. More important to research managers is short-term feedback to identify new options and to improve the shaping of technological solutions to farmers' circumstances. NARS have always provided feedback to IARCs on the value of the materials supplied to them through the international trials networks. IARCs, in their collaboration with NARS, widely promote the need for on-farm research in which farmers assess new materials and practices in their own fields. This research is increasingly perceived as the exposure, test marketing, and adaptation of technology options. A recent example from Malawi documents farmers' comparisons of maize varieties for traits important to them; these included yield, processing and cooking efficiency, and storability (Smale and others 1993). Such assessments provide early information on the acceptability of materials and practices to specific farming communities and on the criteria farmers will use in their evaluation.

Recent IARC initiatives have moved this trend further by emphasizing the importance of farmer assessment as early as possible in the choice and design of prototype technologies, including new plant varieties. This approach prevents the waste of scarce human and budget resources on the development of plant types that farmers can easily identify, even in early breeding cycles, as being unacceptable to them.

In a state-of-the-art pilot study in Rwanda, CIAT and NARS staff compared results from farmer and breeder selections of bush beans. They found that farmer participants chose breeders' materials that would perform well in their own home ecosystems. The twenty-one cultivars selected by farmers outperformed their local mixtures 64-89% of the time over a four year period, with average production increases of up to 38%. (Sperling, Loevinsohn, and Ntambovura 1993). Even though farmers' choices had to meet a number of their own selection criteria, planted in their local environments, these cultivars still outperformed breeders' selections in terms of yield—the breeders' primary criterion. In this program, farmers now evaluate cultivars five to seven cycles before they would have been exposed to breeder-selected materials in conventional on-farm testing.

This pioneering study shows that breeders, selecting for wide adaptation at on-station sites, cannot compete with groups of farmers who know their own ecosystems and can recognize key characteristics of cultivars likely to fit them. It is a clear step toward solving the problem of how to meet the needs of the vast diversity of small, resource-poor farmers in dryland agriculture.

Manufacturing companies in the private sector carefully define market niches and create, modify, or repackage products to fit their targets. These Rwandan farmers, all women, carried their knowledge of their local ecosystem, and therefore their own selection criteria, with them to the research station. They were encouraged to use their knowledge, and each left with a mixture of bean varieties she judged best for her own circumstances. More such mechanisms are needed to expose farmers to technology options that may be useful to them. Agricultural research planners make too little use of the strategy, common in the commercial world, of a variety of products appropriate to a diversity of market needs.

Institutional Impact

Horton (1990) identifies the **principal** impact of IARCs as institutional—creating stronger national agricultural research institutions. He includes intermediate technologies as products that strengthen NARS as institutions. This definition supports a point emphasized in the paper: the CGIAR's dependence on the effectiveness of a range of other institutions, particularly NARS. The conceptual framework in Figure 2, however, illustrates the more conventional view that institutional impact improves the functioning of the target institutions.

This conventional definition embraces human resource development through training, a role undertaken by most IARCs in their areas of expertise. From the inception of the CGIAR in 1971 to 1990, IARCs had trained 45,000 developing country scientists. Some 25,000 were trained from 1985 through 1989: more than 9,000 from Africa, 6,600 from Latin America, 6,800 from Asia, and 2,700 from West Asia and North Africa. Most training was in short courses of one week to six months. The five-year total includes 1,012 scientists at M.Sc. level, 786 at Ph.D. level, and 348 in postdoctoral studies. The data show how many attended courses; the impact of this major effort is much more difficult to measure. Although some IARCs do monitor their trainees, they usually do so to improve course content and organization rather than to evaluate their investment. At IRRI, however, training impact has been assessed by criteria such as the professional growth and job productivity of the alumni and their use of the knowledge they gained from their courses (Domingo and others 1989).

Within the CGIAR, the International Service for National Agricultural Research (ISNAR) is responsible for building capacity in organization and management with agricultural research institutions; irrigation management is the responsibility of the International Irrigation Management Institute (IIMI). Indicators of successful implementation are problematic in these areas, because there is no satisfactory way of evaluating investments in institutional capacity building by IARCs. But CIMMYT has attributed the fall in the coefficient of variations of its yearly international maize trials, from 25 percent in 1974 to 16.5 percent in 1982, to learning through collaborative interaction between center and national scientists (Byerlee and Moya 1992). Internal reports from IARCs highlight that, although scientists from developing countries appreciate training, the lack of opportunity to mobilize new skills because of moribund institutions reduces morale and increases staff turnover. In Africa, in particular, the financial problems of NARS—low salaries and very low operating budgets—erode the morale of both managers and scientists and often overwhelm efforts to improve institutional effectiveness.

Scientific Impact

Some of the original IARC directors saw publication as incidental to their mission. Recently, since strategic research has been cited as the most appropriate focus for the CGIAR, the five-year external reviews of the centers have increased their emphasis on evaluating publication records. Citation analysis is an accepted measure of scientific impact. Among IARCs, ILRAD—wholly devoted to strategic research—has a strong record. Other high performers include ICLARM and the International Food Policy Research Institute (IFPRI). Such analyses can readily be obtained for centers, or even center staff, from commercial agencies that specialize in citation.

Impact Independent of Farmer Decision Making

The impact of IARC research on the lives of resource-poor farmers is the dominant preoccupation of CGIAR stakeholders and scientists. As Figure 2 shows, this can occur independently of farmers' decisions. The best-known example from CGIAR research is the control of the cassava mealybug by IITA and its partners in Africa, using aerial diffusion of a parasitic wasp (*Epidinocarsis lopezi*), identified as a mealybug predator by CIAT in Latin America. This sophisticated application of biological control resulted in enormous savings of staple food across the cassava belt of Africa. An independent evaluation of the program (Norgaard 1988) estimated minimum benefits of $2.2 billion by the year 2003, for an expected total expenditure of $14.8 million during the period 1978 through 2003. The fact that this program will be active for a twenty-five year period (even though this solution bypassed the farmer decision-making, adoption, and diffusion process) again shows the long time horizons involved in R & D.

Such opportunities are rare. Crops such as cotton, for which the farmer sells the seeds in the course of marketing the unginned lint, allow improved seed to be distributed back to growers. The rate of diffusion in these circumstances depends on two factors: the amounts of breeders' seed made available, and the efficiency of the collection of cotton and the distribution of seed. Even with farmers as a captive market, however, materials cannot be imposed on them; their circumstances still need to weight the direction of the breeding program. For example, the introduction of Akala and Deltapine cotton varieties in Turkey in the 1960s created a situation in which a high proportion of cotton had to be picked in a short period of time, requiring large amounts of casual labor that was expensive and difficult to find. The traditional varieties fruited over a longer period, spreading the demand for labor to a level that could be provided by the family. Farmers responded by reducing their area of the crop (Kiray and Hinderink 1968).

Impact in Farmers' Fields and Beyond: Levels and Methods of Assessment

The key to economic, social, and environmental benefits from research investments is to design technologies farmers **choose** to use. As Figure 2 indicates, farmers' decisions to adopt new technology bring impacts at the farm household level, on family income and welfare and on the physical and human resources used in farming. Economic repercussions extend beyond the farm, through the markets that receive the increase in production and supply the new fertilizers, herbicides, and pesticides. If the scale of adoption is broad enough, these repercussions are felt in the regional, national, and even the global economies.

Impact on the farm household is the most common and probably the most useful level for IARCs to monitor to generate information for internal planning and donor interest. Measures of impact start from counting "adopters," farmers who use the technology. For example, a *CIMMYT on-farm research project on maize* in Panama focused on the maize/bean rotation system. After four years, 61 percent of farmers had adopted improved weed control, and 43 percent had adopted some form of reduced tillage; 35 percent had adopted improved varieties by 1985 and 74 percent by 1989, and the use of row planting had increased from 30 to 80 percent (CIAT, CIMMYT, and CIP 1992). In this study, adoption was used as a measure of success, and researchers assumed that farmers adopted the new varieties and techniques because they brought benefits.

Historically, much impact assessment has been based on measuring the change in the productivity of the crop or animal enterprise using the new technology. This approach requires more than simply identifying adopters. Extra data might include:

- the land area or number of animals to which the new technology is applied;
- the yield increment to the technology;
- increased stability of yield over time and reduction of risks;
- the cost reduction achieved when lower costs are the source of benefits;
- the net benefits obtained (the value of the incremental yield less the costs of obtaining it); and
- the contribution of each component of the technology (the variety and each new management practice) to the yield increment and sometimes to the net benefits obtained.

CIAT and NARS in Colombia and Venezuela implemented an integrated pest management program for rice, based on economic thresholds, which illustrates both cost reduction and environmental impact as sources of benefits. In Colombia, the total insecticide and fungicide applications were reduced from nine per crop cycle in 1980 to three in 1990. In Venezuela, monitoring began in 1988 when more than 60 percent of farmers made two or more applications; by 1990, more than 90 percent were making one application at most (CIAT, CIMMYT, CIP 1992).

Evaluation on a Farming System Level

Beyond the enterprise, at the level of the whole farm, the analysis of benefits is more complex, more detailed data are needed, and the cost of impact assessment increases. Interactions among the enterprises bring "opportunity" costs and benefits into the calculation. In smallholder agriculture, with subsistence for the family a high priority and family labor the major input, evaluation at the whole farm level is an imperative.

A comparative evaluation of the use of fertilizer on cotton and maize in the same farming system showed widely different results between an enterprise basis and a system basis in which the interaction between enterprises in their demands for labor and cash are accounted for. On an enterprise basis, fertilizer showed a cost/benefit ratio of 3.6:1 on cotton compared with 3.1:1 on maize. On a system basis, fertilizer on cotton showed a return of 3.1:1 compared with 4.8:1 for maize, reflecting a reversal of choice for investing very scarce cash in fertilizer (Collinson 1968). This case illustrates the importance of evaluation within the whole system for smallholder agriculture. It also illustrates the extra data collection costs needed to capture labor profiles for the whole farm system. A full month-by-month profile of labor use by enterprise and by operation is required to identify the interactions that influence how farmers choose to invest in fertilizer. Although the enterprise is a valuable context for the generic evaluation of prototype technologies, only evaluation in the whole farm system can identify options and adaptations that address the priorities and circumstances of the farmers in *that system*.

A similarly intensive study recently reconsidered the impact of the green revolution on the poor. It compared the change in incomes of different classes of rural people in rice-growing villages in southern India and concluded:

> ...evidence from the resurvey villages shows that small paddy farmers (+90 percent) and landless laborers (+125 percent) gained the largest proportional increases in family income between 1973/4 and 1983/4.... These changes are corroborated by measured changes in the real value of household consumption expenditure, by a sharp improvement in calorie and protein intake, and by the growing importance of higher quality foods in total household expenditure (Hazell and Ramasamy 1991).

The complexity, cost, and time required make such a study a "one off" event and render this level of detail impractical as a routine follow-up to farmer innovation. Even this intensive state-of-the-art study may not capture the social costs or benefits from such innovation. The sustainability issue revolves around external factors—practices that degrade natural resources and generate costs that are avoided by the individual but fall on society as a whole. The measurement of such externalities, including resource and environmental degradation, is the subject of intensive contemporary research. To date there are no accepted methods of measuring the costs and benefits of this dimension.

Evaluation on a Global Level

When a new technology has been widely adopted, its aggregated effect on crop production can be used through national statistics to make estimates of impact, even on a global level. Some global and continental impacts of the green revolution's short-strawed rice and wheat varieties have been noted. On the whole, because of the time required for adoption to be reflected in national production statistics, they are of limited use for feedback to adjust ongoing programs. Furthermore, as Table 1 shows, aggregate national data, particularly for crops used heavily for farm family subsistence, can be unreliable. Finally, cause and effect are less easily related at the aggregate level. Production can rise from increases in the area planted as well as from yield improvements. But where national data are reliable (particularly where land use areas and yields are well documented or survey data can be linked to increases in seed or input sales), they are cheap to obtain and analyze and offer strong reinforcement to donors of money well invested in the past.

Table 1

Comparative Cassava Production Figures for Nigeria, 1979-82 (in thousands of tons)

Year	Federal Office of Statistics	Central Bank of Nigeria	Food and Agriculture Organization (UN)	U.S. Department of Agriculture
1979	1,621	1,976	10,500	14,600
1980	1,492	1,988	11,000	13,100
1981	872	2,159	11,000	11,800
1982	943	2,308	11,700	11,700

Source: Stifel 1992.

In some cases, centers have collaborated with and supported government statistical departments, supplementing the data to be captured in routine sample surveys. One recent example is CIAT in collaboration with the Government of Rwanda, where new varieties of climbing beans were reported to be popular among farmers. In 1992, CIAT collaborated with both the Département des Statistiques Agricoles, which regularly documents trends in the 93 percent of Rwandan households that are dependent on agriculture, and the Institut des Sciences Agronomiques du Rwanda to evaluate the spread of climbing beans. They have always been popular in the Gisenye and Ruhengeri areas of the north and west, but surveys as late as 1986 showed that only 5 percent of farmers in the central and southern areas grew climbing beans. The 1992 sample survey, however, reported **improved varieties** of climbing beans on 43 percent of farms, representing 450,000 rural households. Estimates from the survey, carried out in one of Rwanda's two bean seasons, gave an annual value of net benefits of between $4 million and $8 million for Rwandan farmers (Sperling 1993).

This type of documentation has increased during the past two years. Table 2, from a recent publication by the Latin America-based centers, demonstrates the impact of their collaboration in germplasm development with the national programs in the region (CIMMYT, CIAT, and CIP 1992). Benefits from the improved materials have been allocated equally between IARCs and NARS.

For beans, maize, rice, and wheat, the impact for which is clearly documented, the annual value of increased production is $1,050 million, or nearly ten times the **total** 1990 budgets of the three centers combined. Because international markets for rice and

Table 2

Progress in Genetic Improvement in Beans, Maize, Rice and Wheat in Latin America Until 1990

Achievement	Beans	Maize	Rice	Wheat
Number of released, varieties, lines, or both orginating from CGIAR centers	95	86	69	134
Area grown with these varieties, 1990 (thousands of hectares)	370	2,002	1,208	4,074
Number of varieties released with parental material from centers	8	111	60	272
Area grown with these varieties, 1990 (thousands of hectares)	60	1,848	800	4,550
Crop area affected by centers' germplasm, 1990 (%)	4.9	16.7	25.1	81.2
Estimated extra production from these materials, 1990 (thousands of tons)	122	1,696	836	3,523
Estimated extra value, 1990 (US $ millions)	60.8	203	209	567
Price saving to consumers, 1990 (%)	5	0	24	0
Costs of centers' research programs, 1990 (US $ millions)*	5.3	6.6	4.0	6.4
Internal rate of return on research programs up to 1990	16	56	69	67

* Includes overhead.

Source: CIAT, CIMMYT, and CIP 1992.

beans are limited, as production went up, prices went down, making consumers the principal beneficiaries of new technologies for these crops. Thirty-three varieties of potatoes developed at CIP have been released in Latin America, but the impact has not yet been documented. For other commodities, such as pasture and cassava, research started from a much more limited knowledge base, and impact is only now being observed.

Economic Models

Aggregate production data can be multiplied by the price of the product to give a simple economic valuation of benefits. Such simple valuations, however, do not reflect the full economic consequences of the increases in production, because the impacts of technological innovation are confounded by the effects of changing market prices and changing policies on the target crop as well as by the effects of similar changes on other crops. In addition, although more efficient production means cheaper consumer prices, it may also mean changed demands in the labor, machinery, and supplies markets.

Economic models capture these repercussions and offer an aggregate measure of the economic gain created by technological innovation. The internal rate of return, shown in the final line of Table 2, is one such measure. Based on the gain created, it specifies the rate of return to the investment in germplasm research. A detailed description of types of economic models and a list of results from their application can be found in Evenson (1992).

Such models have their disadvantages. For nontechnical audiences, they offer less transparent results than the less sophisticated aggregated adoption, area, and production data, and they identify cause-and-effect relationships less clearly. As mentioned earlier, diverse agencies contribute to the total R & D process and thus to the CGIAR's dependence on others to mobilize its products. It is often unclear in model applications whether the benefits that stream from new technology are appropriately allocated over the full range of investments that contribute to technology adoption and diffusion.

As in a recent CIMMYT study of wheat research in Nepal, it is often appropriate to acknowledge that innovation would occur without a national research program—in the Nepal case, as spillover from research in India and Pakistan. In this study, the returns to research are measured by the economic gains accruing to the investments made by the national research program, net of the contribution of the spillover and of the returns to investments by other sectors in the R & D process (Morris, Dubin, and Pokhrel 1992).

Finally, it is important to note that the international centers have wider criteria for success than economic surplus alone. They are interested in alleviating poverty, reducing farmers' risks, and sustaining the natural resource base. Although economic models can be used to show the distribution of benefits between producers and consumers, they cannot yet capture the other dimensions important to the mission of the CGIAR centers.

Challenges and Strategies for IARCs

The centers must help donors assure their constituencies that investments in research are valuable. They must also meet their own needs for priority setting and program planning. The centers are most efficient in producing intermediate products that are useful to many countries. Such products need further research to tailor them to farmers' circumstances. Beyond that, institutional and policy support are also needed to enable farmers to exploit these products.

Historically, researchers in general, and particularly international researchers, have depended on others to identify the technology needs of small farmers and to mobilize their research results to meet those needs. This dependence is the first major challenge for IARCs because researchers feel pressure to justify their work in terms of progress in development, without having any influence over many of the factors that propel development (Hardie 1988).

The difficulty of linking research to the market has long been acknowledged, in industry and in private-sector agricultural research. For each product that succeeds in the market, a typical manufacturing company generates fifty-eight new product ideas. After business analysis, seven of these generally reach the development stage. Of these seven, six are eliminated during development, testing, or commercialization. Almost 75 percent of new product expenses (and thus the work of eight out of ten development scientists and engineers) are devoted to projects that will not be justified in terms of commercial success (Booz, Allen & Hamilton Inc. 1968). The preceding example reflects an average success rate of 14 percent for the manufacturing companies surveyed. It demonstrates that research cannot be planned with certainty. Serendipity remains an important element.

In agriculture, the vagaries of the weather are an added source of uncertainty. Production, and therefore farmers' incomes, varies from year to year. This uncertainty also complicates and often prolongs the research process. DeKalb Seed Company makes some 5,000 crosses to identify one new commercial maize hybrid. Pioneer Seed Company has released an average of twelve commercial conventional hybrids per year during the past decade on an annual budget of approximately $19 million. Although similar data for CIMMYT cannot be used as a test of comparative performance, they are of interest. National programs in developing countries released more than 300 maize varieties or hybrids containing CIMMYT material between 1981 and 1990 (Table 3), an average of thirty per year on an annual average maize program budget (including overhead) of approximately $12 million (CIMMYT 1992).

Improved maize based on CIMMYT materials now covers just less than 10 million hectares—or some 12

Table 3

Maize varieties and hybrids containing CIMMYT germplasm released in developing countries, by region, 1966-90.

	Releases containing CIMMYT germplasm			
	Code 1	Code 2	Code 3	Total
Sub-Saharan Africa:				
1966-70	0	0	3	3
1971-75	4	1	6	11
1976-80	6	4	3	13
1981-85	13	14	25	52
1986 90	12	17	20	49
Total	**35**	**36**	**57**	**128**
WANA:				
1966-70	0	0	0	0
1971 75	0	2	0	2
1976-80	0	1	0	1
1981 85	1	2	0	3
1986-90	0	4	0	4
Total	**1**	**9**	**0**	**10**
Asia:				
1966 70	0	0	3	3
1971-75	0	0	2	2
1976-80	6	1	9	16
1981-85	9	2	22	33
1986 90	10	7	33	50
Total	**25**	**10**	**69**	**104**
Latin America:				
1966-70	8	3	9	20
1971 75	4	2	8	14
1976-80	6	11	6	23
1981 85	26	16	33	75
1986-90	12	23	36	71
Total	**56**	**55**	**92**	**203**
All developing countries:				
1966-70	8	3	9	26
1971-75	8	3	8	29
1976 80	18	16	6	53
1981-85	48	33	33	163
1986 90	34	47	36	174
Total	**116**	**102**	**92**	**445**

Code 1 = Direct use of CIMMYT germplasm.
Code 2 = Selection from CIMMYT trials.
Code 3 = Contains some CIMMYT germplasm.

Source: Lopez Pereira, M.A. and M.L. Morris. 1994. Impacts of International Maize Breeding Research in the Developing World, 1966-90. Mexico D.F.: CIMMYT.

percent of the total maize area of developing countries. These numbers reflect the situation of many dryland crops in agricultural sectors dominated by small farmers. The potential for further impact remains huge; achieving it will require governments and the international community to address the performance of complementary functions essential to the R & D sequence, such as produce marketing, farm input supply, farm credit, and extension services. Research will not always be the priority candidate for investments. Unfortunately, the adaptive research function remains weak. There is only very sporadic coverage of small-farm sectors by cadres that understand communities and can enroll farmers in partnership by the use of participatory techniques. This direct exchange between researchers and resource-poor small farmers is a prerequisite for better market information and better balance in the demand for and supply of technology.

The second major challenge faced by IARCs is their diversity of products with a clientele that is scattered across the developing world. A typical center may interact with thirty national programs and have considerably more than 100 research projects. The cost of assessing the impact of these projects on so many clients is prohibitive, especially because weak agricultural statistics mean that primary data must be collected to measure impact in most partner countries.

The key to monitoring, evaluation, and impact assessment is the same as that for better articulation of small farmers' technology needs: an institutionalized cadre of professionals with skills at the grassroots level to whom this work is routine. Continual interactions with farmers and communities, an integral part of the adaptive research function, generates powerful feedback on the effectiveness of the R & D sequence. From experiences with a variety of farm-level models, a consensus is emerging that a participatory approach that mobilizes both the communities and the public service together will make good use of scarce professional resources. A concerted effort to rationalize this grassroots function would widen coverage and generate information for better decision making at the program and policy levels.

Planning

Monitoring the research cycle is important to IARCs. Preliminary assessment and intermediate feedback, within the timeframe of the cycle, are particularly important to priority setting and program planning. Evidence of early adoption, or early farmer assessments, offer the benefit of timely feedback to modify continuing programs.

Special studies of final impact are of little use to program planning because the R & D cycle through diffusion of the technology to final impact assessment is too long. IARC programs normally will have moved on before the results of such assessments are available to feed back into the planning process. Where research for better solutions will continue, the impact of an earlier iteration can measure the residual benefits for the evaluation of further research. At the same time, special studies of final impact do add to our knowledge of the technology adoption and diffusion process. When this kind of research is undertaken, an explicit aim in its planning should be to use the information for as many purposes as possible to offset the heavy overhead costs of primary data collection. Subsequent studies can be integrated with the collection of government agricultural statistics where this is dependable and where there is similar value to NARS partners in demonstrating the success of previous investments of public funds.

Wherever primary data collection is planned and the products of more than one IARC have helped to improve local farming, there is scope for intercenter collaboration in sharing fieldwork expenses.

Donor Needs

Donors that sponsor development are interested in the effectiveness of their funding. The current recession coincides with a burgeoning demand for aid for Eastern Europe, for United Nations activities, and for the environment. The scarcity of funds has sharpened donors' interest in evidence of impact, and IARCs are responding, some more strongly than others.

Preliminary assessments of the potential impact of research are valuable to donors, particularly when a research calendar highlights mileposts as intermediate steps toward solution of problems and adoption of the technology by farmers. Although they are not measures of impact, such achievements allow donors to monitor progress and help reconcile them to the longer time horizons of strategic research programs.

The expansion of research on natural resource management in the CGIAR will involve longer-term programs and less definable products. In many cases, the product will be an understanding of natural processes and the avoidance of losses, often measured in terms of topsoil saved, intact groundwater, or other external factors. Clear preliminary planning is needed before investments to realize such products will be accepted. Planning should emphasize intermediate achievements and projections of the expected social benefit of resource management interventions. One dimension of the ecoregional strategy recently adopted by the CGIAR is to show early benefits to the production system in which sites are located; an understanding of the interactions between human decisions and natural resource processes accumulated over the long term.

The CIMMYT data in Table 3 illustrate the recording and presentation of intermediate achievements. By maintaining a data base of plant material sent to national programs and the pedigrees of materials released by them, CIMMYT is able to highlight the importance of its germplasm. These are milepost achievements that demonstrate the effectiveness of the center's partnership with national programs on three continents.

Donors use the documentation of final impact to demonstrate the success of their funding in their domestic budget process. Because studies of final impact are expensive and must be selective, the aim is to show examples of high returns on IARC investment. Benefit flows can evaluate returns beyond the costs of the immediate program, for example, against the total investment in research in the commodity and even against the investment in the center as a whole.

Although economic models are useful for such studies, for the greatest impact it is important to document farmers' adoption, improvements in household situations, any differential impact on livelihood between men and women, and the aggregate impact on production. Such parameters add value for public relations purposes and for donors. IARCs think that such studies should be done in partnership with national programs, to help convince their Ministries of Finance to improve research funding as an investment in the nation's future.

IARCs also bring significant returns to the domestic agricultural economy of some of the CGIAR's major donors. Quantifying these returns can be valuable to future center support. To date, only Australia has quantified the benefits it has received from improved wheat materials made available from CIMMYT:

"Since 1977, Australia has contributed an average of US$2.8 million per year to core programs of the CGIAR Centers. Of this some 6% has gone to CIMMYT's wheat program . . . Australia has received overall cost reductions averaging some US$75 million per year resulting from the improved wheat varieties derived from CIMMYT" (Brennan 1989).

The Brennan study attracted wide attention in Australia:

"Mr John Kerin, Minister for Primary Industries and Energy, recently announced that the use, in Australia, from 1974–1990, of wheat germplasm imported from CIMMYT has resulted in additional income for the wheat industry of over two billion dollars—a sum sufficient to fund both ACIAR [the Australian Council for International Agricultural Research] and Australia's contribution to the CGIAR at their present levels for the next 100 years!" (Tribe 1991).

There is also an important educational task in raising awareness among donors and their constituencies on the nature of the research process. Their expectations should be based on an understanding of two characteristics of the process: the uncertainty of research as a business and the time it takes to complete.

Conclusion

Research initiatives are defined by the problems they seek to solve, not the product they hope to identify. Failure is common. Even with success, the final nature of the product, and therefore its congruence with market needs, is initially unknown. These uncertainties are heightened by the difficulties of identifying market needs among small farmers to help shape the product as the research process progresses.

Better market information will reduce the failure rate of new technologies and enhance the efficiency of the research process. This can be achieved by wide promotion of and support for adaptive research, and by rationalization of the organization of field-level staff working in research, extension, and evaluation. Rationalized field-level organization can easily provide periodic impact assessment information for clients ranging from research managers to policy makers and donors. Routine information flows from the field will enhance the relevance of decisions at each of these levels to the needs of developing country rural populations.

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