CIMMYT 1991 ANNUAL REPORT

INTERNATIONAL MAIZE AND WHEAT IMPROVEMENT CENTER

IMPROVING THE PRODUCTIVITY OF MAIZE AND WHEAT IN DEVELOPING COUNTRIES: AN ASSESSMENT OF IMPACT

CONTENTS

CIMMYT's Mission
To help the poor by increasing the productivity of resources committed to maize and wheat in developing countries while protecting the environment. We do this through agricultural research and in concert with national research systems.

Cover photo by G. Hettel:
Shallow-well irrigation of wheat in Bangladesh.

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IMPROVING THE PRODUCTIVITY OF MAIZE AND WHEAT
IN DEVELOPING COUNTRIES: AN ASSESSMENT OF IMPACT

K. Elsesser

CIMMYT's efforts to help the poor in developing countries have combined extraordinarily well with those of national programs. Together we continue to improve the lives of literally hundreds of millions of poor people. In this *Report*, we look at the effectiveness of international maize and wheat research from several angles.

Comments From Management

T. Luba

In 1991, CIMMYT commemorated 25 years of service to the developing world. We approached that anniversary confident of past contributions but certain that daunting challenges remain — poverty, the well-being of women and children, and protecting the environment. In anticipation of the event, we focused attention on an evaluation of our efforts, emphasizing impacts on productivity. We had two reasons for doing so. One was to develop for donors and others evidence that investments in CIMMYT have been well placed; the other was to orient our resource allocations in the future.

We initiated our impact study shortly after International Centers' Week 1989. At that time, too, we decided to feature its results in our next presentation to the CGIAR during ICW '91, and in our *1991 Annual Report.*

Having decided to emphasize impact here, there remain a myriad of new developments from our research that we cannot describe. Readers should be aware that the sources of future impact are under development, that good progress is being made, and that there are many new stories to tell.

Recognizing that the assessment of impact is not a trivial task, we invited Dr. Jock Anderson, a professional with considerable experience in this arena, to comment on the subtleties of such work (see Point of View, pages 8-15). His observations will be useful to all readers of this *Report.*

About CIMMYT's Impact Study

We are now well along in our study of impact and it is evident that the benefits of the undertaking easily justify the effort. We contemplated the relative merits of doing the job with our own staff in partnership with national programs or through an independent contractor. The latter might bring more credibility in some circles but the former had the advantage of bringing our own knowledge to bear on the process, especially the crucial information about germplasm held by our plant breeders, and of adding to our own knowledge of what is transpiring with our products. We chose the first option and realize now that the knowledge of CIMMYT staff was crucial to the task. Beyond that we simply could not have completed the study without the detailed knowledge and contributions of national program staff.

Another critical decision was determining the point at which impact should be assessed. While a range of options were considered, in the end we agreed to focus at the level of the farmer, concluding that only if change occurred in farmers' fields could we point to impact. We recognized that many steps intervene between research results at CIMMYT and the utilization of those or related results by farmers, and that the chain can be broken at many places along the way because of considerations well beyond our influence. Nevertheless we agreed, as we had earlier in framing our strategic plan, that CIMMYT's mission requires change to be measured at the farm level.

In organizing for the study we were aware of certain critical considerations in assessing impact. One of these rests on the problem of attribution (see Point of View, page 14). While our purposes, especially those related to our future priorities, would have been better served had we been able to isolate the effects of our own efforts, it was clear that impact is the joint product of national programs and of CIMMYT, and that separation of the effects is simply not feasible.

We recognized the advantage of separately assessing impact in each of several product areas. The most important was germplasm improvement and, given the limitations on attributions, we set out to assess the broader effects of germplasm improvement in maize and wheat, but concentrated on those materials which are in some way related to the Center's work. So, too, with the other dimensions of our work that were assessed — crop management research, training, information, and knowledge generation. In none of these arenas is the contribution uniquely CIMMYT's; indeed, in most cases a worldwide network of researchers is involved.

> The poor have been the major beneficiaries of our efforts, especially from the impacts associated with germplasm improvement.

We were aware of the importance of accounting for the ways in which the poor have benefitted from our work. While we have not yet done so, our data will permit us to assess the relative impact on poorer as distinct from better off developing countries. However, it will not permit us to say much directly about influence on given groups within countries. We believe, however, that the comparisons made possible by our study, coupled with inferences based on other sources, will reveal that the poor have been the major beneficiaries of our efforts, especially from the impacts associated with germplasm improvement.

We wanted to ensure that our sense of impact had a temporal dimension. We wanted to know the impact of the near past as distinct from that of our earlier past. That made it mandatory to date the results we were studying, adding to the demands of the effort. Even so, the findings clearly justify the extra complications as we have a good sense of the continuing contribution of CIMMYT's work and can, in some cases, be optimistic about what is likely to occur over the near future as recently released materials make their way into farmers' fields.

We would have preferred to see impact described in terms of the value of the extra returns as compared with the costs associated with achieving them. We are proceeding on the cost side, reviewing the resources dedicated to maize and wheat research by each national system. This information will be the basis for future reports that focus on the returns to maize and wheat research in several developing countries. For now, results in hand go no further than estimating the area covered by new materials in the case of germplasm improvement and less far for our other products. We intend to pursue ever closer approximations to added returns. We believe such estimates will be of importance to donors and will help us as we shape resource allocations within the Center. Moreover, it is clear that our experiences can serve as a basis for similar analyses by national programs, with accompanying benefits to their planning.

We began with a questionnaire sent to all major maize and wheat producing countries in the developing world, with the exception of most of China. For various reasons, little of our past work has been directly relevant to their needs. (I add that more and more collaboration is emerging with China and that CIMMYT germplasm, especially subtropical maize and spring bread wheat, is playing an ever expanding role in breeding work there.) We consider major producers to be those countries that produce over 100,000 tons of grain or at least half of their domestic requirements. These account for over 95% of the developing world's production, outside China. We also obtained information from a number of private sector maize companies on the extent to which their releases included materials directly related to CIMMYT's work. We seemed to get reliable responses (see box, page 20).

Questionnaires were distributed via our regional staff, who then worked closely with colleagues in national programs to assemble the data. While some information was readily available, much was not, e.g., while records of varietal releases were ready to hand, information on pedigrees frequently had to be constructed by specialists. Harder still was estimated areas now under various varieties. This topic was approached through reviews of on-farm studies, through seed sales, and through the knowledge of those familiar with activities in the countryside. We noted that information on wheat is more readily available than that on maize, probably because improved materials are more easily identified and because wheat has been studied more than maize.

We also conducted a comprehensive review of the literature accumulated at CIMMYT and in national programs, covering yield gains, on-farm adoption studies, and so on to support and corroborate the various analyses being made. Not infrequently it was advantageous to go back to our sources and check, challenge, or reaffirm earlier information.

Past Accomplishments

The major results of the effort to date are reported in the Review of CIMMYT Programs, pages 16-28. As indicated there, we have achieved much. There is ample evidence of the tremendous

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The value of CIMMYT's impact study rests on the high quality of the data we gathered. Our staff worked closely with national program colleagues at all levels, assembling and reviewing information for the study.

impact of the work on wheat. Beyond that, and immensely satisfying, our work continues to be important to national programs as evidenced by the new materials incorporating recent CIMMYT advances. In maize we have the sense that national programs are poised to distribute a wide range of useful materials and can see that, if the earlier relationship holds between the release of varieties and their utilization by farmers, we can expect a notable increase in farmer applications of our work on maize.

Less satisfying were the results from other parts of the study. There was little evidence of impact via work on crop management research. A host of considerations influence the utilization of such research and virtually none of those are under the control of CIMMYT or indeed of the national programs where most of our work on crop management has been realized. While good examples can be found[1] of payoffs that clearly rest directly on undertakings involving significant inputs by CIMMYT, the lines of cause and effect are notably more tenuous in the realm of crop management research than in the domain of germplasm improvement. This is not surprising — most such studies have turned up similar results — but it is nonetheless discomfiting.

As for training, results were necessarily measured through intermediate products, that is to say we simply report on the number of participants in our training programs. We can draw some inferences about their own contribution to increasing productivity in agriculture, e.g., through the work by national programs on varietal improvement, testing, and diffusion. Similarly, for information we can easily summarize the preparation and distribution of outputs, but we cannot connect them directly to results in farmers' fields. And, finally, our contributions to new knowledge could be assessed only through the number of publications and, perhaps more meaningfully, through the number of citations. What is evident is that the numbers of both are rising, and that conforms well with the course we laid out in 1988 with our strategic plan. I add in passing that our continuing efforts to assess impact will extract stronger conclusions about these dimensions of our work and will add assessment of impact on the protection of natural resources. Indeed, on this last we are now involved in ascertaining how we can best approach the theme.

We believe that our donors, in particular, will welcome the results of this study. Varieties directly related to CIMMYT's work account for 80% of the developing world's wheat production (outside of China) and over 10% of its maize production, with rising numbers promised in maize for the near term given the events of the recent past. That news must surely gratify those who have invested in the Center's work.

[1] See *Planned Change in Farming Systems: Progress in On-Farm Research,* ed. Robert Tripp (Chichester: John Wiley & Sons, 1991).

N. Russell

One encouraging sign of progress revealed by our impact study is that national programs are providing farmers with ever more productive maize varieties. As those cultivars spread, they will make a considerable difference to those "living on the edge" in rural areas.

Insights for the Future

Though we can take great pleasure from the past our major interest is with the future. I believe that the study is instructive there, too. First, it offers CIMMYT management additional insights into how we should orient our resources. What emerges largely reaffirms the findings of our recently updated strategic plan. When we first prepared the plan, however, we were looking to a future with more resources. The reaffirmations are even more important to us as we look to a future with fewer resources. It is doubly important that we assess options well as the opportunity costs of CIMMYT's remaining resources, especially our human capital, will now be even higher because of their greater scarcity. The study results will be valuable in that process. And as donors look toward the future, they should know that the elements which led to the successes of the past — the quality of our people, the structures for decision making, the pragmatic culture, and the working relationships with national programs — are still in place, offering every promise for further successes.

The evidence cited in this report (and in many other sources) shows continuing high returns to the poor through investment in CIMMYT. If we juxtapose those findings with a general awareness that growth in agriculture will be an imperative for developing countries, that improved technologies will be crucial to that growth, and that effective research will be critical to the formation of improved technologies, then surely all this suggests increasing budgets for CIMMYT's work. It is more than ironic, then, that we confront not increasing but decreasing budgets.

> Looking to the future, the elements that led to the successes of the past are still in place, offering every promise for continued success.

Financial Circumstances

CIMMYT's spending reached US$35.7 million in 1991. Some $26.3 million were allocated for essential activities, $8.09 million for complementary work, $.94 million for auxiliary services, and $.36 million as capital funds. These allocations were derived from $27.2 million in core funding and $7.5 million in special projects, as well as auxiliary services revenues of $.98 million.

Of continuing concern was the contrast between Mexico's inflation and its devaluation of the peso against the dollar. The result was a CIMMYT-wide dollar denominated inflation of some 11.6% in 1991. Beyond that, and a greater threat to our work in the long run, was the budget shortfall experienced by the CGIAR. This led to a further reduction in our 1991 funding. Fortunately, the two effects had been forecasted and we continued the directed program of belt tightening and downsizing initiated during the final days of 1990. We will maintain this strategy during all of the coming year.

For the rest, the resolution of uncertainties with one of our major donors has settled cash flow problems that plagued us most of the year. We ended the year in sound financial condition and with sufficient reserves to meet the costs associated with the downsizing required to meet our new financial circumstances.

To Conclude

To return to the beginning of these comments, we celebrated CIMMYT's 25th anniversary at the end of 1991. One of the featured elements of that event was the recognition of the immense contributions the Center has made. Beyond that, discussion turned to the future, with papers on the interactions between agriculture and the environment, the likely course of science and its implications for our work, and the probable utilization of maize and wheat over the next two decades. Invited guests included some of those who were with the Center in 1966 and responsible for what have become the hallmarks of the Center. A large number of colleagues from Mexico attended, as did many donor representatives. What emerged from the exchanges was the sense that CIMMYT has played a powerful role in the past and that the elements are in place for it to do so through the next decades. I trust you will find supporting evidence for that sense of optimism in the pages that follow.

Donald L. Winkelmann

Donald L. Winkelmann
Director General

Point of View

S. Pasten

Measuring the Efficacy of International Agricultural Research

Jock R. Anderson*

Readers of annual reports from the International Agricultural Research Centers (IARCs) are no strangers to the roles and functions of the Centers and, accordingly, most of these are taken as understood in what follows. There are, of course, many ways of considering what elements are essential in the purpose and functioning of a modern IARC. A Center is certainly an intermediary in the flow of scientific information and materials from many sources, including labs in more-developed countries, towards the betterment of life in many places, most especially in less-developed countries. This aspect of a Center's work — its role as an intermediary, whereby it amplifies various inputs into a range of different research outputs — is the focus of this essay.

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Rather than try to encompass the increasingly broad spectrum of agricultural research activities in the expanded and probably still expanding CGIAR System, the intention here is to focus on the somewhat simpler and more specialized activities of a Center that is primarily directed at crop improvement. CIMMYT is an important example of a such a Center, and it is surely appropriate here to draw upon its experience for illustrative material.

The Key Inputs

The primary "given" for a Center is its mandate, which has tended to be one of growing responsibility and something of a "moving target." Donors, clients, and Centers themselves change over time in their perceptions of the importance of different features of a Center's mandate, and these changes eventually get translated into formal and probably ever more ambitious statements of fundamental purposes.

Another encompassing input is the budget. In the early days of the CGIAR, budgets grew easily and rapidly in nominal and real terms. That has usually not been the case in recent times, and the more "mature" Centers such as CIMMYT face a special difficulty: their effectively shrinking budgets hardly match an enlarged mandate.

Human Capital

The vital input with which a Center works — people's productive skills — can be summarized in terms that some may regard as superfluous economists' jargon. "Human capital" in the present context logically begins with the members the governing board. These people bring their own experiences to the charge of helping a Center fulfill its mandate. Wisdom, by definition, is a scarce commodity, and sometimes, given the bounded terms of tenure on boards, it is at least debatable whether the best available talent always has been harnessed for the overall governance of a Center. On the other hand, tenure seems sufficient to provide linked continuity of service and guidance. In this regard, the persistent influence of the Rockefeller Foundation agricultural sciences establishment, for instance, is surely notable in CIMMYT's evolution for its continuance before and since CIMMYT came under the CGIAR.

A critical set of human capital components of a Center is the internationally recruited staff. They bring to their work their own informal experiences in agriculture, formal scientific training in various parts of the world's educational systems, and their own research and other relevant experiences in other organizations — not to mention their personal intuition and imagination. Typically, a Center's human resources are admirably diverse, encompassing a great spectrum of cultural and linguistic backgrounds and often, but some would argue not as much as would be desirable, a wide range of educational backgrounds.

Materials

The physical materials with which a Center works deserve special mention. Depending on the nature of the Center, the types of materials brought in may be deliberately highly variable. To fulfill their mandates, plant breeding centers such as CIMMYT require the ability to draw upon the collections of plant genetic resources that have been assembled by other agencies in other places, whether these be gene banks or breeders' collections from throughout the world. The Centers thus bring together new acquisitions and combine them with externally preserved materials to select for and stabilize improved cultivars that reach the less-developed world.

Knowledge

Of central importance in this recombination process is the role of ideas and knowledge. Aside from the knowledge brought to bear by a Center's human capital components, the CGIAR System features other sources of cogent advice. The Technical Advisory Committee (TAC) is one such source (although its other roles sometimes get in the way of this particular one). The network of contact and collaboration with people outside the System is certainly a critical source of knowledge. The more formal manifestations of this contact are the pages of scientific journals and the scientific press, as well as research conferences and other forms of research visitation (which some have unkindly designated "development tourism").

A further source of advice orchestrated by TAC is the process of periodic external review, which most Centers, especially CIMMYT, complement with their own internal reviews to make the external processes more efficient.

The world "priorities" has not yet been mentioned in this already lengthy list, but advice on priorities is inherent in the mandate, the budget, the review processes, and continuing counsel from TAC. At best, the many forms of advice on priorities may be thought of as rather crude sign posts along the dusty road towards successful research, on which the drivers really making the progress are the research workers vigorously applying their skill and imagination.

A Center's Role in the Research Business

Several aspects of a Center's role have already been implied in the foregoing discussion. The Center itself formalizes and embodies the institutional arrangements that are created to seek and receive the relevant inputs to be transformed creatively into novel products. Center-centric activities can be considered briefly in two ways, one relating to organization, and the other to a Center's style of research.

Organizational Matters

Myriad organizational arrangements must be addressed in institutionalizing a successfully productive research system. Geographical considerations arise early in the process. The location of the headquarters for a research Center must be decided; for global or other widespread crop improvement programs, it is necessary to think of how and where outreach work can be facilitated. The physical aspects of a research complex must also be addressed, although some Centers have managed to use existing national program facilities with minimal new infrastructure.

Management is yet another element of the research "multiplier" processes that might be considered in either a policy analysis of desirable change or an assessment of the efficacy of the overall research process. The managerial intensity imposed upon a Center is an important organizational matter. It has been claimed that one positive advantage of a typical IARC is the low level of bureaucratic inertia — inertia that might otherwise be imposed through overweighted managerial structures. Perhaps such a sanguine view is no longer so relevant. It is also conceivable that Centers are now generally better managed than they once were under more freewheeling arrangements.

Style of Research Function

Many elements constitute the "style" of a Center's research. The one emphasized here is the intensity of modes of collaboration with research colleagues in national agricultural research systems. Collaborative styles vary greatly among Centers and national programs, depending on their respective stages of development. Clearly, most Centers (and certainly CIMMYT) must deal with many different types of national systems, whether the differences relate to the size of a commodity research program or the scope of the work undertaken.

In recent times, the "mandate-expansion movement" has tended to acknowledge the enhancement of research capacity in national systems as an explicit objective of international agricultural research. Whilst this idea is significant for the long-run development of global agricultural research, to the extent that it implies a major commitment to formal training per se, it is not so obvious that such an additional objective should be lightly added to a Center's mandate. Mandates aside, effective collaborative arrangements mean that national program capacity is fostered through partnership arrangements wherein joint research ambitions are pursued together.

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Outputs: The Subject of Efficacy and Impact Assessment

Any comprehensive discussion of the efficacy of the production of research outputs relative to inputs can best be addressed through a series of topics that reflect the range of research products that must be considered in a decent documentation of performance. Although it is tempting to employ the frequently used word "impact" as shorthand for the fruits of international agricultural research, the word has so many unfortunate connotations that this temptation is largely resisted here. Indeed, it was resisted almost comprehensively in the 1984-85 "Impact Study" of the CG System (Anderson, Herdt, and Scobie 1988) that this commentator had the dubious good fortune to direct (see box, page 13).

Materials

In the case of CIMMYT, improved cultivars are, unsurprisingly, the foremost outputs to assess. They constitute the living materialization of the work of the Center as it builds upon its source germplasm and combines serendipitous selection, insight, imagination, and sheer hard work into products judged to be superior in some way or variously assessed as "improved." Whether or not a cultivar really *is* improved in a particular circumstance is a further subtle question that must be addressed in any evaluation that pretends to be complete. It turns out, however, to be a rather tricky "judgment call" in most cases. Under irrigated conditions of production with fairly benign climatic variation, it may be fairly easy to assess a degree of improvement in yield, quality, and disease resistance. Under non-irrigated, sometimes semi-arid, or at least variable rainfed conditions, such an appraisal is a non-trivial exercise. It probably takes at least several cropping seasons of careful comparison to produce results with any low level of ambiguity. Farmers naturally have to make their own judgments about such matters before they take up newly released cultivars in any significant manner, and so several groups of people involved in the process are obliged to make somewhat analogous judgments.

The most painless way of dealing with this question is to stand back from the process and observe what farmers themselves do. To the extent that they quickly and widely take up new materials, all parties concerned, including both research and extension services, can feel comfortable that they have indeed achieved a worthy degree of improvement in the cultivars offered to the farming community.

Cultivar releases are, in principle, the most straightforward elements of an impact assessment to describe. It will be clear already, however, that even this assessment is not particularly straightforward. The IARCs share plant materials at different stages of genetic development with national programs. Another complication is the dispersed nature of the information on who uses the improved materials once they are released, at what intensity, and under which circumstances. The costs of gathering such information, particularly on any wide geographical scale, are considerable. Any careful impact assessment is thus potentially a costly affair, and when donors and others call for documentation of research efficacy, they need to be alert to the diversion of scarce financial resources from other research activities towards a formalized account of research consequences. The same point applies naturally to all types of assessment and to the performance elements mentioned below, although for brevity it will not be emphasized further.

Methods and Management

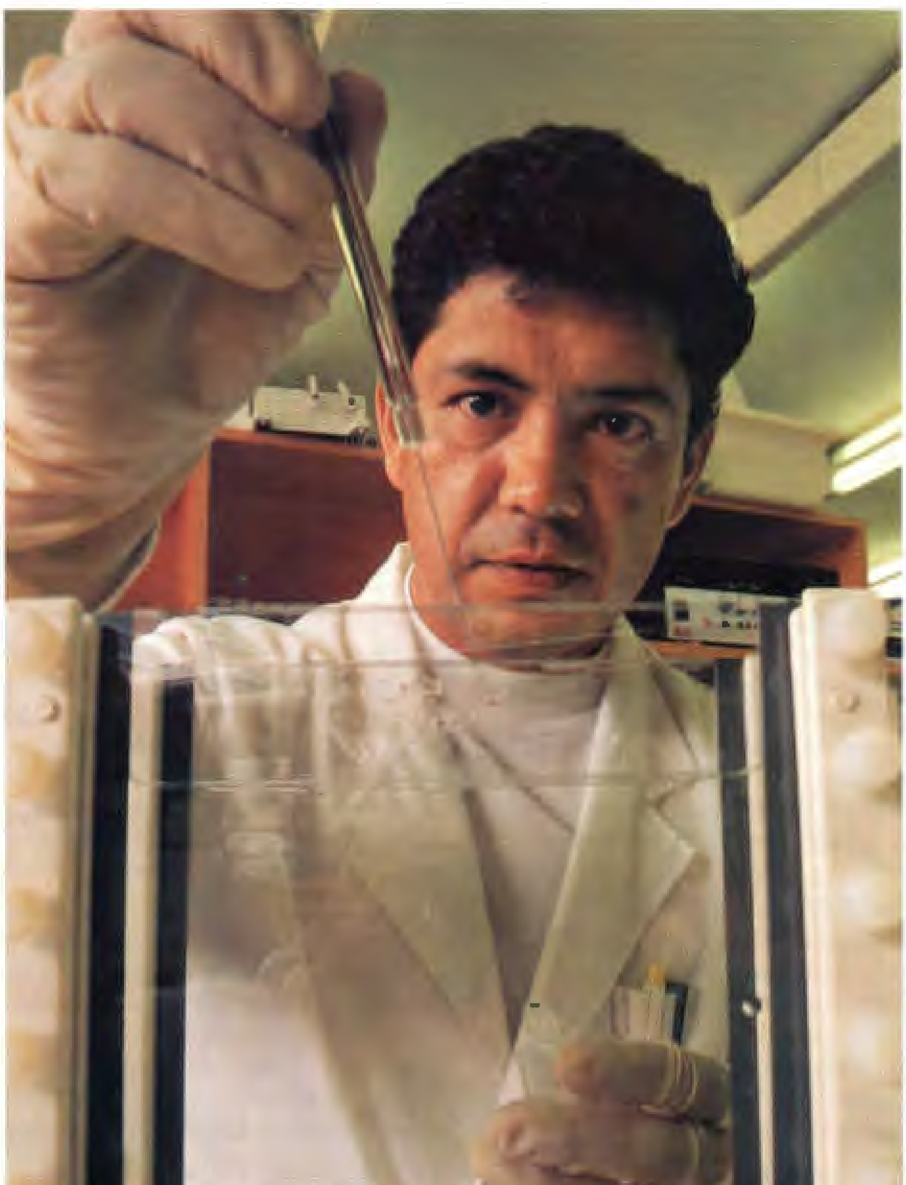
Counting new cultivar releases and measuring areas sown to specific cultivars is awkward enough. The difficulties are greatly compounded when comparable assessments must be made of methods, say, of crop husbandry, that may be traceable to the research activities of a Center. Many agents are involved in advising farmers how better to manage their farm resources, including new cultivars; for one thing, the private sector is often heavily involved in such work through its desire to sell inputs to farmers. Perhaps these difficulties explain the limited documentation of the effectiveness of work described under the broad heading of "crop management research." This is not to say, however, that such documentation will be unimportant. Indeed, some have argued that crop management research will be the major means of technological advance in the post-Green Revolution era — in addressing "second-generation" problems.

The difficulties become even greater when estimating and assessing the effects of crop management research on the underlying productivity of the agricultural resources base. To see this, one has only to reflect, for example, on the technical difficulties of measuring soil loss under alternative crop-management practices, or the pollution of groundwater and downstream flows through inappropriate use of agricultural chemicals.

Human Capital Increments

Moving up the scale of difficulty of research product measurement, it is appropriate to consider the surely significant way in which a Center's activities impinge upon the human capital of many agents, including collaborative scientific workers in national programs, as well as through increasingly experienced and more knowledgeable Center staff themselves. The measurement challenges are profoundly great in assessments that properly go beyond mere headcounts of involved individuals and formally trained participants in the many different training activities organized by Centers.

Consider, for example, the way in which CIMMYT might work towards building up the human capital in the wheat research program of a particular country. The national research staff in the country will have had their own formal training in both national and foreign universities, as well as possible formal training visits to CIMMYT and other IARCs. They will also have interacted professionally with a wide range of kindred scientific souls, both



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Human capital — the fusion of each person's individual experience and training — is a "vital input" for effective agricultural research.

within CIMMYT itself and in other agencies. To ask then what CIMMYT has done for national capacity today or tomorrow in such a country is a highly sophisticated question to which there could not possibly be a good and ready answer. An example of the supplementary questions one would like to ask is: How much better is the national program now able to function compared with how it would have functioned without the various contacts with the Center? This kind of counterfactual question is at the heart of any assessment of human capital development and does not get any easier to answer, which is why only a paucity of material on this matter is available. The costs of such careful analysis will be significant indeed, surely rivalling the costs of some training activities themselves.

Knowledge Increments

The contribution made to human knowledge through investment in a Center is doubtless the most difficult output to measure. Contributions to knowledge are sometimes measured in the crudest form by numbers (or word counts and other attributes) of publications offered to posterity in the scientific literature. A large and complex scientific literature must be confronted in this work. Scientific journals vary greatly in the rigor of their standards for assessing and accepting works for publication. Some would argue that any given piece of "scientific" writing can be published, providing that the quality of the journal is not a severely binding constraint.

Even if an assessment were restricted to more formally evaluated contributions to knowledge, it would still provide a narrow view indeed of the knowledge-incrementing processes with which all actors in the international and national research communities must work. The difficulties here are sufficiently obvious for this commentator to leave their resolution to those possessing either the bibliometric inclination or scientific perspicacity to judge how such contributions might usefully be measured.

CGIAR Impact Study

The 1984-85 Impact Study of the CGIAR System was conceived by a group of pro-active CG donors as one way of addressing concerns expressed in some quarters about what the investment in the System had achieved and whether it was a Good Thing. From its inception, the study was ambitious. It was to include all of the (then) 13 Centers (that is, irrespective of age and maturity); to span past, present, and future "impacts"; and to cover all effects on all affected people, wherever they were. In the end, however, many selective judgements had to be made about the study's contents.

Considerable effort went into dealing with thematic issues cutting across the work of several Centers, including plant genetic resource management and exploitation, agricultural engineering, biological nitrogen fixation, and similar scientific matters, as well as the wider economic consequences of research, such as the adoption of modern crop varieties.

Some Center products are not as readily measurable as the spread of "new" cultivars. Accordingly, special attention was given to assessing work oriented toward agricultural policy or agricultural research organization. As noted in the present text, a great many other actors are involved in these activities, making any assessment of "impact" intrinsically difficult.

There was an overarching desire that the Impact Study should take a client-oriented view of Centers' work. Much effort went into conducting case studies in some 30 individual countries, looking at what all of the elements of the CG System had achieved through their respective collaboration with agencies in each country. Some general findings supported by the study:*

- The CG System was instrumental in helping many developing countries reap high returns from research.
- Benefits from adopting modern varieties were remarkably evenly distributed among farmers differing in size of holding and land tenure status.
- Through their training programs, the Centers raised the capabilities of thousands of developing country researchers.
- Emphasis on the human aspects of technological advances grew along with farming systems research; nevertheless, important areas such as the participation of women farmers and women researchers needed attention.
- Research on policy issues promoted policy decisions that positively affected food production and consumption.
- The challenges facing many Centers were so exacting that it was too soon to expect impressive returns from their work. However, it was noted that, "at almost every center, if just one major project meets expectations, it will generate returns far exceeding the cost of the Center."

Was the study worthwhile? Certainly many points emerging from the study — for example, the need for a more client-oriented, responsive, and diverse approach to collaboration from the Centers, the need to cover important gaps in commodity and other research of the System, and the need for sustained, effective investment in international agricultural research have been taken up through various developments in the System. Again, many persons were involved in bringing about those changes; those who worked on the Impact Study would be appropriately humble about their contributions to them.

* See *Summary of "International Agricultural Research Centers: A Study of Achievements and Potential"* (Washington, D.C.: CGIAR, 1985). See also Anderson, Herdt, and Scobie (1988).

Productive Effects

All the elements of agricultural development discussed above have real value only to the extent that they can contribute to enhanced productivity and welfare in farming systems and among those who consume their products, most specifically in the less-developed parts of the world. To link these several products in a consistent framework for measuring productivity is challenging enough. To go further and quantify the welfare implications through the way such products are used and played out in development is quite another matter, which, to the best of this commentator's knowledge, has not been fully explored and may never be. Economists refer to some of these considerations as dealing with the "equity issue," for which the efforts of Lipton with Longhurst (1989) provide a significant illustration. We need to be quite humble about the actual possibilities of assessing "research impact" holistically and to be modestly realistic when considering what information may turn up through any such formal assessment.

Partitioning the Contributions to Research Performance

The question of how to partition the contributions to research performance — to determine who did what to whom and how — is intrinsically difficult to address and, for reasons to be advanced here, may best be regarded as a non-problem because it probably need not be squarely faced. The virtues of avoiding direct confrontation with the issue are discussed below.

Attribution

I would argue (Anderson 1987) that, without extremely careful and thus expensive individual case-study analysis, it is simply impossible to determine the relative contributions of collaborators in research activities that are intrinsically joint. One can perhaps make a case that, to the extent that improved access is provided to international collections of germplasm, the international dimension of the effort is important — but just about the same case can be made for nearly every aspect of subsequent innovative activity, whether it be selection, testing, or release. Thus the assessment of impact in this respect necessarily must deal with the *gross effects* of the collaboration and regard the research performance linked to a Center as also representing the contributions of the national partners in the collaboration.

Displacement Accounting

It is salutary to reflect on what happens when a new and improved cultivar is adopted. Something gets pushed out, and increasingly these days, it is quite likely to be a cultivar that was already regarded as improved. The importance of acknowledging this "roll over" in cultivars is to recognize their finite life and thus the confined period over which the productivity benefits of their spread are realized. This distinction has not always been carefully made in some adoption studies, which have focused on comparing only the incidence of improved versus traditional cultivars.

Productivity Changes

Production is an intrinsically multi-factor phenomenon. The production function that comprehensively ties together the contributions of the many factors such as land, labor, capital, technology, etc., is seldom if ever clearly known. If one is focusing on the consequences of having improved cultivars available, and is endeavoring to assess the productivity implications of this, it would be necessary, in principle, to take account of all changes in the productive environment, including changes in factor-use intensity and mix, as well as the changes related to use of the new cultivars themselves. Again, even in some of the most careful studies, these types of analyses have seldom been attempted, let alone successfully accomplished.

To assess the productivity implications of [using improved cultivars], it would be necessary, in principle, to take account of all changes in the productive environment, including changes in factor-use intensity and mix, as well as the changes related to use of the new cultivars themselves.

The Role of Policy

Yet another complicating difficulty of assigning effects to particular causes when several are potentially involved relates to the policy environment in which agriculture takes place. Policy makers have many opportunities to influence the profitability of particular technological practices, so when it comes to assessing who did what, and how, and when, it is arguable (at least in some cases) that changes in policy may have been even more significant than the technological research itself in engineering particular technological adjustments. Within the broad policy arena, there are also many actors at several levels of national systems as well as those in extra-national bodies, whether these be international research Centers themselves or other concerned international agencies (such as development banks, trade-liberalization organizations, or whatever).

Conclusion

This catalogue of difficulties is intended to depict the many intrinsic problems that need to be overcome in assessing the efficacy of a Center's productive enterprise. It might be interpreted as implying that such assessment is so difficult and expensive that it is hardly worth undertaking. This may well be true, but the political reality of contemporary funding mechanisms means that such a divorced position cannot be maintained. There are so many seemingly imperative needs for "impact assessment" that some investigations of this type must perforce proceed.

Just who should do the work is something of an open question. Tradeoffs must be made between the plausibility that should accompany "independent," detached external assessments and the cost-effectiveness of more informed, targeted, and less detached internal assessments (Anderson and Herdt 1990). At what stage this work may best be done is another question that probably has no really defensible answer. Each research product has its own life cycle, and a study at any given time will identify different impacts at different stages of evolution. The purpose of any impact study must thus be well articulated to guide choices as to stage, product emphasis, geographic scope, precision of measurement, and other parameters.

Amongst the present community of IARCs, CIMMYT has shown a remarkable willingness and even enthusiasm in confronting these difficulties and documenting important aspects of what has in many cases been clearly a successful activity. Its critics will say that, at least for parts of its mandate, CIMMYT has had an "easy row to hoe," and that in some sense it is not "fair" to crow too loudly. The user and donor communities, however, can be thankful that CIMMYT has taken such leadership in this work and has thus helped to ease the path for others who must also go down it. The information assembled elsewhere in this *Report* attests to a laudable degree of impact and efficacy that, in the grand scheme of things, has come at a remarkably small social cost yet with an impressively large social gain. Information of this kind will be crucial in underpinning arguments in the halls of power and — one hopes — will bring enduring funding for the long-term processes of discovery which will, in turn, help achieve global food security in the decades and centuries to come.

J. Longmire

Many factors determine the extent to which the work of agricultural researchers benefits specific groups, and it is difficult to precisely ascertain whether the effects of research are equitably distributed.

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Review of CIMMYT Programs

N. Russell

Improving the Productivity of Maize and Wheat in Developing Countries: An Assessment of Impact

"The biggest impact . . . for its development dollar, bar none." So said the late Dr. Frank Meissner, creator of the Inter-American Development Bank's Agricultural Marketing Section, about the return to their investment in international agricultural research. His generous endorsement is carried in the Bank's 1991 publication, *Seeds of Change*. The following pages lend support to that assessment with clear evidence of the impact of maize and wheat research for developing countries.

In 1990, CIMMYT began a long-term study of its impact in developing countries. That effort started producing results in 1991, some of which are highlighted here.[1] The survey and evaluation methods used and some of the challenges associated with such work are described elsewhere in this *Report* (see Comments from Management, pages 2-7, and Point of View, pages 8-15); here we focus mainly on outcomes.

The results reported here, however, should not be seen as the last word on impact, but rather as preliminary data that will undergo revision and refinement over time. We now have a comprehensive database on the use of germplasm related to the Center's work, which we call "CIMMYT germplasm" for the sake of brevity, while recognizing that many others — especially our colleagues in national programs and, of course, farmers — contribute to its development and eventual use. This database also includes information on farmers' adoption of varieties based on CIMMYT germplasm and other materials. We still lack adequate information and methods for the much more difficult task of accurately gauging benefits and estimating their economic value. Even so, information from a wide variety of sources suggests a sizeable payoff from our work and that of national programs. And while we believe that all our major activities produce useful results, we still have much to do before we can make clear and objective assessments of crop management research, and of our work in training and information (see Comments from Management, page 6). This *Report* therefore focuses on the impact of germplasm improvement research, by far CIMMYT's largest enterprise.

Maize and wheat improvement research is now characterized by a high degree of international cooperation, and progress at the farm level reflects the success of a truly collaborative effort. That close collaboration — so essential to success — often makes it difficult to separate the results of CIMMYT's work from that of our colleagues in national programs. Still, we *can* assess the broader effects of germplasm improvement in maize and wheat, and in some cases draw conclusions about the impact of materials that are in some way related to the Center's work. We do this, however, only to get a sense of the returns to investment in CIMMYT. Farm-level success with improved maize and wheat varieties still hinges on close collaboration with national programs.

In determining where particular varieties came from, we saw reason to be conservative. This is especially true in the case of maize, whose ability to outcross makes it difficult to establish how much CIMMYT germplasm is in a given open pollinated variety (OPV) or hybrid. With a self-pollinating crop like wheat, on the other hand, genealogies are more transparent. We start here by pointing out patterns in the release of varieties (regardless of source) and then go on to indicate trends in the use of CIMMYT germplasm.

Patterns in the Release of Maize and Wheat Varieties

Maize

We know from our study that just over 1,000 OPVs and hybrids have been released by national programs since 1965. With each five-year interval since then, the number of releases has risen steadily (Figure 1). Two noteworthy patterns:

- Among materials released by public-sector institutions, OPVs have predominated, accounting for about 60% of the total. The remainder are hybrids. A little more than half of all released materials are adapted to the lowland tropics and the rest to the subtropics, midaltitudes, and highlands.

- There is considerable variation among countries in the number of releases, ranging from 4 in Togo and Uganda to 85 in Mexico. Still, the number of maize varieties released apparently has little to do with the strength of the national program. Some of the most accomplished in

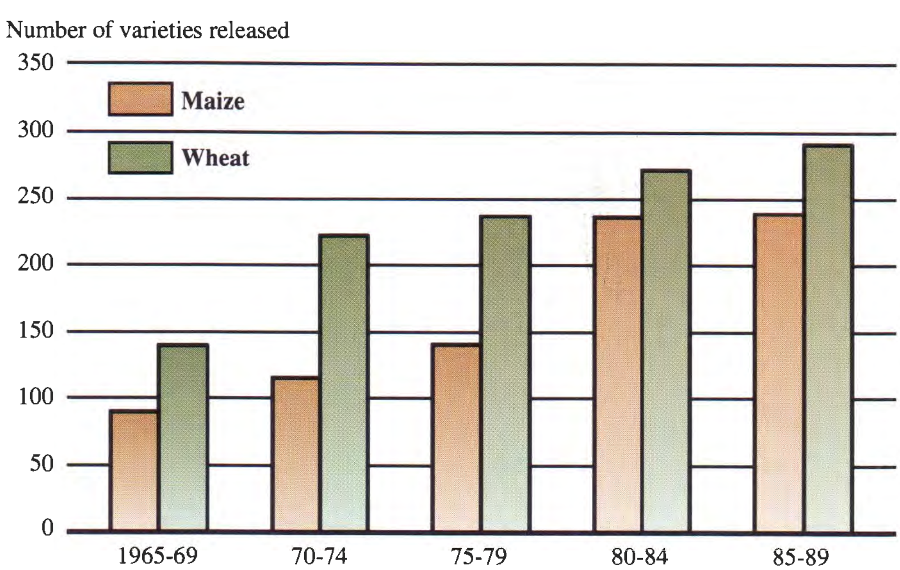


Figure 1. Trends in the number of maize and wheat varieties released, all countries in survey, 1965-89.

[1] The information presented here is drawn from *A New View of the Impact of Technological Change in Maize and Wheat in Developing Countries* (Mexico, D.F.: CIMMYT, 1991), which synthesizes major conclusions from several draft papers prepared during the year. Two detailed technical bulletins on the impact of CIMMYT's maize and wheat research will be published in the near future.

maize breeding (Brazil and India, for example) have released the fewest varieties per million hectares of maize area.

Wheat

Our inventory of wheat cultivars includes more than 1,300 varieties released by national programs, nearly all of which have entered the market since 1965. Since then, the number of releases has risen steadily (Figure 1). Notable patterns:

- Over 80% of released varieties are spring bread wheats, which account for 77% of total wheat production in the developing countries included in our study.

- The number of varieties released is not closely related to wheat production. National programs in Latin America released nearly half the varieties included in our database, even though the region accounts for only 10% of total production in developing countries.

- The proportion of varieties developed for rainfed areas is clearly increasing, and by now some 50% of all new releases are aimed at non-irrigated environments.

The Origin of Maize and Wheat Varieties

Maize

On the basis of survey results, we were able to divide maize varietal releases into the following categories:
1) those containing no CIMMYT germplasm, 2) those containing some germplasm from the Center, 3) materials from our international trials that have undergone selection for local adaptation, 4) direct introductions of our experimental varieties, and 5) varieties with germplasm developed by CIMMYT in cooperation with the International Institute of Tropical Agriculture (IITA). These categories were further simplified for graphical presentation (Figure 2). We also attempted to gauge the use of our materials by the private sector through a limited survey of seed companies in developing countries (see box, page 20). Major conclusions from our analysis:

- The proportion of commercial maize varieties related to CIMMYT's work rose steadily from 1970 to 1989. Seventy-five percent of the varieties released by national programs during 1985-89 contained our germplasm (Figure 2). Of all the varieties and hybrids released in developing countries since 1965, about half now contain the Center's germplasm.

- Our materials have been used quite extensively to develop OPVs (Figure 3). Among releases containing CIMMYT germplasm, materials adapted to the lowland tropics predominate. Superior materials are now available for other germplasm categories, as well, and their use by national programs — and eventually by farmers — is expected to increase significantly.

- CIMMYT maize germplasm has been used most intensively by national programs in Latin America and least by those in the West Asia/North Africa (WANA) region.

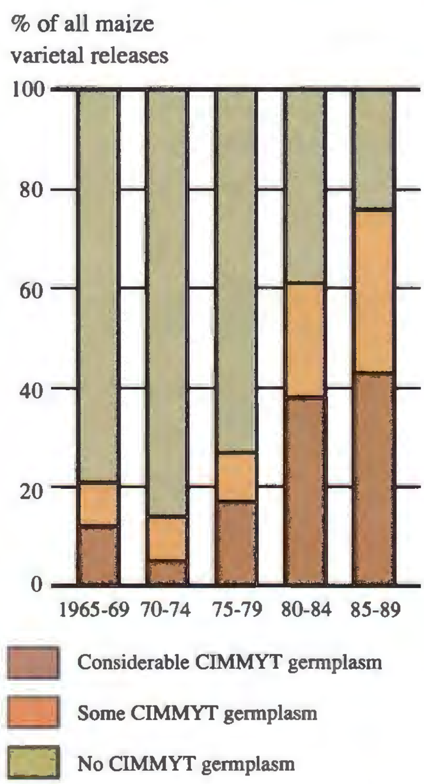


Figure 2. Use of CIMMYT maize germplasm by national programs in developing countries to produce commercial varieties, 1965-89.

Note: Most materials developed at the International Institute of Tropical Agricultural (IITA) were classified as having some CIMMYT germplasm. A few of those materials, however (such as the TZPB-SR series developed from our Tuxpeño Planta Baja population), were classified as containing a considerable amount of CIMMYT germplasm.

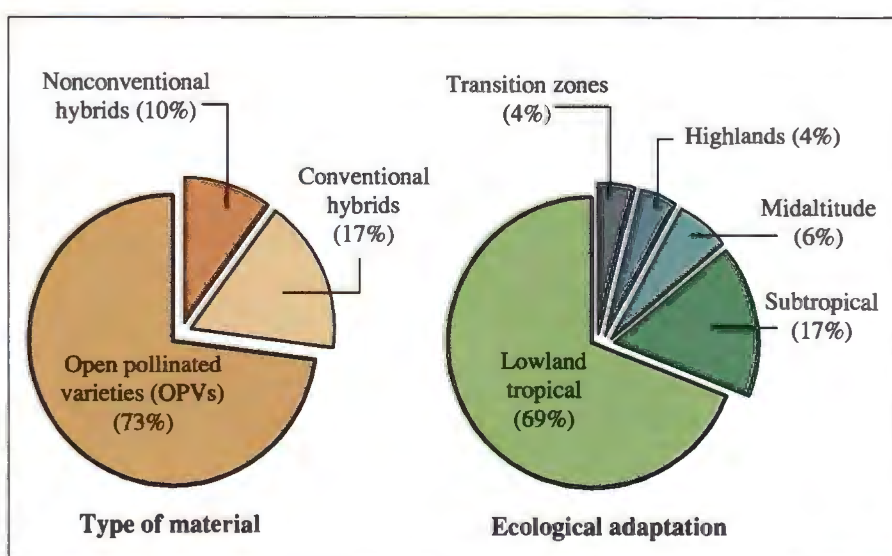


Figure 3. Maize releases containing CIMMYT germplasm, by type of material and ecological adaptation.

- How national programs use our maize germplasm is clearly related to breeding capacity. Whereas the stronger programs tend to carry out further improvement of our materials, others are likely to release it with little modification.

Seventy-five percent of the maize varieties released by national programs during 1985-89 contained CIMMYT germplasm. Varieties related to our work now occupy about 30% of the total maize area planted to improved cultivars.

Wheat

In documenting the use of CIMMYT wheat germplasm, we divided all of the released varieties into three categories: 1) those based on Center lines or selections from our nurseries, i.e., germplasm resulting from crosses made by our staff, 2) crosses made by national programs, in which at least one of the parents was obtained from us, and 3) crosses made by national programs, without using CIMMYT germplasm as one of the immediate parents. (Often, however, our materials occupy a more distant place in the genealogy of these varieties.) Major findings include:

- The proportion of commercial wheat varieties related to CIMMYT's work (categories 1 and 2) increased steadily from 1965 to 1980, levelling off at about 75% for all wheats (Figure 4). During the 1980s nearly half the varieties released were based on crosses made by Center staff in Mexico.

- Some 90% of all spring bread wheat varieties released in the 1980s are semidwarfs, nearly all of which have CIMMYT germplasm in their backgrounds.

- In the development of spring bread wheat varieties, our germplasm has figured most importantly in the WANA region, where over 75% of the varieties released contain materials generated at Center headquarters or in our cooperative program with the International Center for Agricultural Research in the Dry Areas (ICARDA). CIMMYT wheats are used least in sub-Saharan Africa; still, over half the varieties released there contain our germplasm. The generally strong national programs in Asia draw heavily on our materials, but are more likely to employ them as parents in their own crosses than to use crosses made by Center staff.

- In every region there is a distinct tendency for smaller programs to base their released varieties more on our materials or those from other countries than on their own crosses. As expected, stronger programs rely more on their own capacity to develop commercial varieties.

Use of CIMMYT Maize Germplasm by the Private Sector in Developing Countries

CIMMYT is committed to expanding the options of resource-poor farmers in developing countries, and we pursue this commitment through national agricultural research systems, especially the publicly funded research programs that we view as our primary clients.

Private companies, however, also open options for farmers. Such companies, especially those dealing with seed, are alternative suppliers of improved germplasm. To the extent that their objectives coincide with ours, we attempt to honor their requests for germplasm.

In meeting seed requests, we give first priority to publicly funded national programs in developing countries, followed by private cooperators, national private seed companies, and multinational private seed companies. When national programs wish it, we channel our deliveries to private companies through them.

From our limited survey of private seed companies in developing countries, it appears that more than 25% of the materials they have released (all hybrids) contain CIMMYT germplasm (see table). The companies that use the Center's materials most extensively include those located in some of the largest maize producers among developing countries, such as Brazil, India, Mexico, and Thailand.

Developing country private sector maize releases containing CIMMYT germplasm

Region	Number of companies responding	Number of releases	Percent with CIMMYT germplasm
Sub-Saharan Africa	6	92	11
Asia	10	58	55
Latin America	18	141	28
Total	**34**	**291**	**28**

- The most popular recent CIMMYT cross is Veery, which was released at least 36 times in developing countries during the 1980s, more than double the number of releases for II8156, the cross that spearheaded the Green Revolution in the 1960s. Large-scale crossing of spring with winter wheat (of which Veery is a product) led to the release of 72 varieties during the 1980s. Their importance will become evident in the 1990s, as they are distributed more widely among farmers and as the stronger national programs use them more extensively as parents in crosses.
- Though the Center has worked intensively on improving winter wheats, per se, only since 1985, over a quarter of the varieties released during the 1980s (not including those in China) are based on our germplasm.

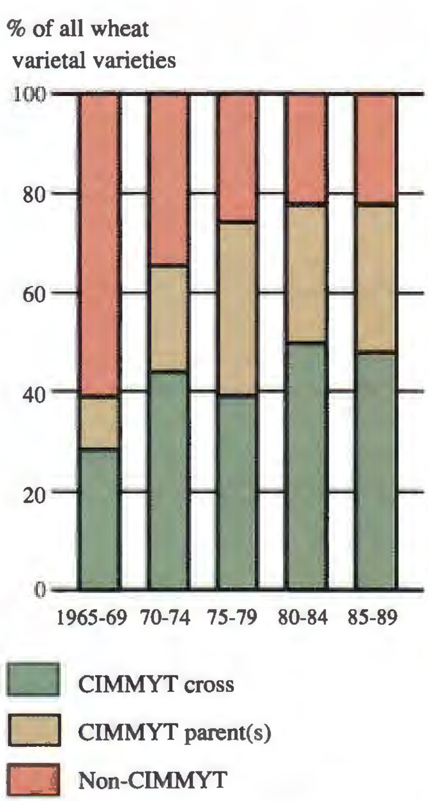


Figure 4. Use of CIMMYT wheat germplasm by national programs in developing countries to produce commercial varieties, 1965-90.

Adoption of Improved Varieties

Given the often formidable obstacles to varietal adoption in developing countries, it is rather remarkable that improved varieties are so widely grown. Poorly conceived agricultural policies, ineffectual seed industries, and weak extension services are among the factors that can impede adoption, and changing these factors is well beyond the purview of CIMMYT and most other suppliers of improved germplasm. And yet, improved maize varieties increasingly find their way into the hands of farmers, and modern, semidwarf wheats have spread very rapidly during the past 25 years.

Spread of the Semidwarfs

By 1969, just a few years after CIMMYT's founding, semidwarf wheat varieties occupied over 8 million hectares in developing countries, or some 15% of the total area devoted to wheat at that time. Since then, semidwarfs have spread steadily at a rate of about 2 million hectares per year (Figure 5). In the 1980s alone, an additional 20 million hectares were planted to these varieties by developing country farmers. By 1990, nearly 50 million hectares, over 70% of the developing world's wheat area (not counting China), were planted to semidwarfs. If we include China, which used dwarfing genes from sources other than CIMMYT, the estimated area planted to semidwarfs rises to about 70 million hectares.

Semidwarfs have been most successful where spring bread wheats are grown. Of the total area covered by spring wheat in developing countries (excluding China), over 80% is planted to semidwarf varieties (Table 1), accounting for more than 90% of the developing world's entire production of spring bread wheat (again, excluding China). For other categories of wheat, especially winter-habit materials, the area occupied by semidwarfs is notably less.

Much of the developing world's production of spring bread wheat takes place in irrigated environments, about which we note:

- By 1980 practically all of South Asia's irrigated spring bread wheat area (a sizeable share of the developing world's total) was sown to semidwarfs. In 1990 these materials covered more than 28 million hectares of irrigated land in the region.

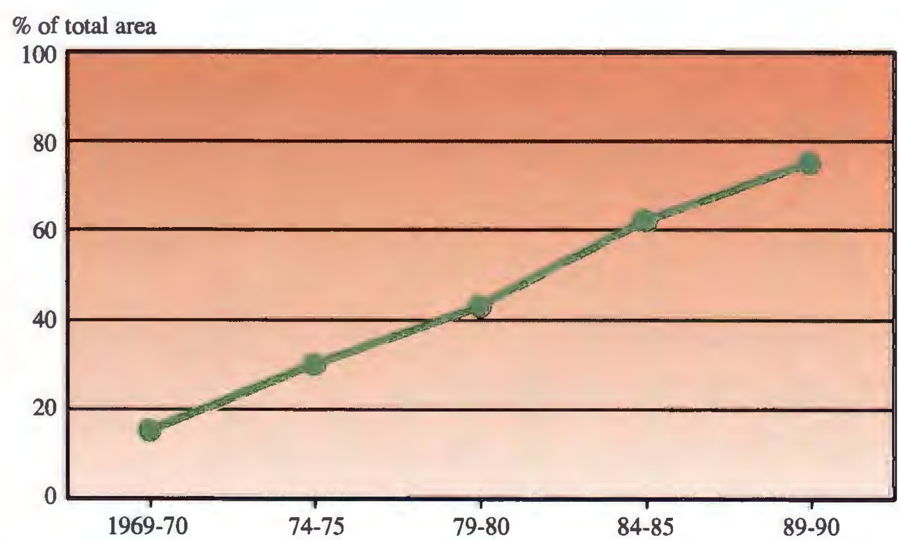


Figure 5. Trend in the adoption of semidwarf wheat varieties, developing world.

- Across all irrigated wheat environments, farmers have replaced earlier generations of semidwarfs at least once and usually twice, though rather slowly in some areas.

In general, semidwarf wheats have been adopted to a lesser degree in rainfed than in irrigated environments. Still, there is evidence that since the 1970s semidwarfs have advanced slowly but steadily into drier areas. The pattern that emerges is one of semidwarf wheats spreading from higher rainfall, temperate locations to drier and often colder or hotter rainfed areas. It is primarily in these more difficult environments, where winter bread wheats or durums often predominate, that adoption of semidwarfs is still limited.

In the rainfed (i.e., non-irrigated) areas of Pakistan, for example, farmers first began to adopt semidwarfs around 1975. By the late 1980s, farmers had taken them up quite widely in medium- to high-rainfall areas, but less so in low-rainfall environments (Figure 6). It seems likely, however, that even the frontier of very dry wheat areas will gradually be occupied by semidwarfs. In Pakistan's low-rainfall environments, Pak 81 (a Veery cross) is now being adopted. Similarly, varieties of bread wheat and durum wheat, based on germplasm supplied by the CIMMYT/ICARDA breeding program, have been released in the WANA region and are showing promise in dry areas. In time these relatively recent products should be taken up on a fairly large scale.

Even so, evidence from other countries suggests that the adoption of semidwarfs in rainfed areas remains incomplete. In Syria and Tunisia, for example, where these varieties have spread gradually in the 1980s, about 30% of the rainfed area is still planted to tall varieties.

Table 1. Percentage of wheat area planted to semidwarfs for different regions and wheat classes, 1990

Region	Spring bread	Spring durum	Winter bread	Winter durum	All
Sub-Saharan Africa	46	18	-	-	35
W. Asia/N. Africa	69	50	17	14	39
South and S.E. Asia	89	-	-	-	87
Latin America	81	64	100	-	81
Total	**83**	**44**	**19**	**14**	**75**

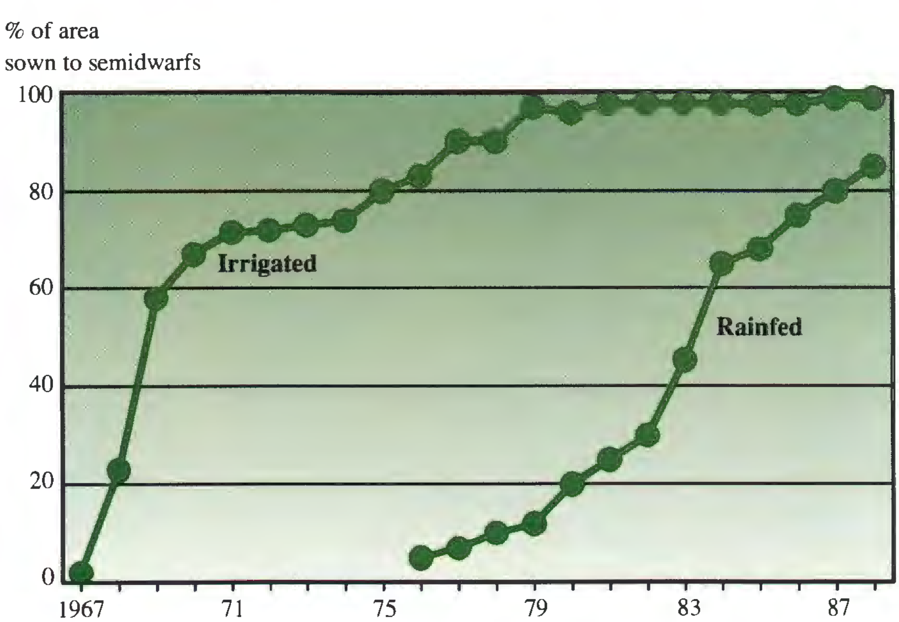


Figure 6. Trends in the adoption of semidwarf wheat varieties in Pakistan's irrigated and rainfed environments.

Use of Wheat Varieties Related to CIMMYT's Work

Though not the only source of semidwarfs, the Center is undoubtedly an important one in developing countries. This fact is clearly reflected in the area planted to varieties derived from our germplasm:

- Overall, varieties to which CIMMYT has contributed directly cover some 36.8 million hectares in the developing world, plus another 10.6 million occupied by semidwarf varieties carrying our germplasm in their ancestries (Table 2). Of the resulting total, nearly 23 million hectares are occupied by varieties based on crosses made by Center staff.

- Apart from Veery, no recent bread wheat crosses have been adopted over a large area (Table 3). The tendency now is for more numerous varieties from various crosses to be taken up over more limited areas. It is unlikely then that a single cross will come to dominate wheat production, as was the case in the early years of the Green Revolution.

Obviously, farmers are happy with the improved wheat varieties resulting from our combined efforts with national programs. However, while older varieties are being steadily replaced by new ones, the rate of turnover appears to be slow. This is particularly true among the larger wheat producers of Asia, where the average age of a variety is more than 12 years. Given that it can take 8 to 10 years to develop and release an improved variety, the overall lag between peak expenditures on varietal development and widespread adoption in the region can reach 20 years. Such a slow rate of replacement hinders efforts to maintain disease resistance and reduces the benefits of wheat breeding considerably (Brennan and Byerlee 1991).

Slow varietal turnover in key wheat-producing regions of the developing world reinforces CIMMYT's strategy of exploring all possible sources of genetic diversity as improved materials are developed. Doing so contributes to genetic diversity in wheat production and limits vulnerability to disease epidemics and other stresses.

In the early years of the Green Revolution, this vulnerability was very real. With surprising speed a small number of semidwarf varieties, having a relatively narrow genetic base, displaced existing varieties over large areas. Since then, however, many new semidwarfs with broader genetic backgrounds than the original Green Revolution varieties have entered the field. This fact combines with the marked tendency toward adoption of greater numbers of genetically distinct varieties over smaller areas to create an important and healthy trend toward greater genetic diversity in farmers' fields.

Table 2. Area in developing countries planted to CIMMYT-based wheat germplasm, 1990 (million ha)

Wheat class	CIMMYT cross	Immediate CIMMYT parent	No immediate CIMMYT parent: Semi-dwarf[a]	No immediate CIMMYT parent: Tall	All
Spring bread	20.6	12.9	9.3	7.9	50.7
Spring durum	2.1	0.1	0.0	2.8	5.0
Winter bread	0.0	1.1	1.1	8.9	11.1
Winter durum	0.0	0.0	0.2	0.9	1.1
All	**22.7**	**14.1**	**10.6**	**20.5**	**67.9**
	47.4 M ha				

[a] Nearly all with CIMMYT ancestry.

Table 3. Area in developing countries under popular CIMMYT crosses, 1990-91

Cross	First released	Area (000 ha)	Country/region
Sonalika	1968	6,250	All South Asia
Veery	1981	3,370	Pakistan, Turkey, Iran, Chile
II8156	1965	1,070	India
Marcos Juárez	1971	860	Argentina
Bluebird	1970	840	Saudi Arabia, Egypt
Anahuac	1975	800	Brazil
Cisne (durum)	1971	460	Morocco, Turkey
Frigate (durum)[a]	1983	480	Syria, Algeria
Bittern (durum)	1979	400	Morocco, Turkey
Others		8,170	

[a] CIMMYT/ICARDA.

Use of Maize Varieties Related to CIMMYT's Work

The danger of genetic uniformity in the maize production of developing countries is far less grave than in wheat. Populations from which CIMMYT generates maize germplasm products are already quite diverse, and our maize scientists, like their counterparts in wheat, actively seek new sources of diversity for key traits. A further consideration (one that will eventually change, however) is that unimproved local varieties continue to predominate in many areas of the developing world. As recently as 1985-87, some 70% of the maize area in sub-Saharan Africa was planted to such materials, 50% in the WANA region, 40% in Asia, and 50% in Latin America, excluding areas that lie in the temperate zone.

Based on survey results provided by national programs in 45 countries (encompassing more than 95% of the developing world's maize area outside the temperate zone), we draw the following conclusions about adoption of varieties based on our materials:

- Overall, nearly 8 million hectares or 13% of the maize area in developing countries (excluding the temperate zone) is planted to varieties containing CIMMYT germplasm (Table 4). This area comprises a significant proportion (about 30%) of the area planted to improved varieties.
- CIMMYT maize germplasm has so far had the greatest impact in the lowland tropics; fully 85% of the area planted to varieties derived from our materials lies within this zone. Excellent materials are now available for other major ecologies, however, and should enjoy wide use during the 1990s.
- Even though national programs in the WANA region have employed our maize germplasm least extensively (as a percentage of varieties released), CIMMYT-based varieties have been most widely adopted there (as a percentage of the region's total area).

While the data behind these conclusions are considered reasonably accurate, we suspect they understate the adoption of improved maize germplasm. Why? Because in estimating varietal coverage we used a very restrictive definition of what constitutes an improved variety. Maize outcrosses readily, so in our study we counted only those areas planted to improved OPV seed purchased within the last three years; for hybrid seed the limit is one year. In other words, the estimated total includes only those areas planted to improved seed that is true to type. It does not take into account the many genotypes in which improved germplasm has assumed a kind of disguise by mixing with local materials.

The Payoffs from Improved Varieties

From the evidence given above, we can draw two fairly obvious conclusions about the payoff from improved varieties. First, it has so far been greater for wheat than for maize. And second, well-watered environments have benefitted more than drier rainfed areas, although gains to farmers in the latter appear to be growing.

Wheat

The yield advantage of improved wheat varieties, their efficiency, and their built-in resistance to major diseases go far in explaining their appeal to farmers. Most of the wheat yield data available come from irrigated areas, about which we observe:

- The adoption of semidwarfs in irrigated environments during the early years of the Green Revolution gave average yield gains of 35-40% (under moderate levels of fertilizer) over the tall varieties they replaced (Dalyrymple 1986; Sidhu 1974; Nagy 1984; Byerlee and Siddiq 1990). Less well known is that during the two decades since then the yield potential of semidwarf varieties under irrigation has continued to grow at an average rate of about 1% per year, or some 20% since 1970 (Figure 7).
- It appears that farmers in irrigated areas have captured a large share of the gains in yield potential. Their high levels of crop management and slow but steady replacement of old varieties with new ones have helped ensure this outcome.
- Yield progress has perhaps not been as rapid where wheat is planted late. This practice is common in many cropping systems, particularly in South Asia, where nearly half of the irrigated wheat is sown after December 1, usually following rice or cotton.

Information on yield gains in marginal environments is less plentiful but provides evidence of progress. It appears that even there farmers tend to capture a sizeable share of the yield advantage offered by new wheat varieties (see box, page 25).

Resistance to major diseases affecting wheat — especially stem, leaf, and stripe rust — has long been seen as a vital complement to high yield

Table 4. Area in developing countries planted to maize varieties and hybrids containing CIMMYT germplasm, 1990

Region	Maize area in 1990 (000 ha)	Area under CIMMYT-related varieties (000 ha)	Area under CIMMYT-related varieties (% of maize area)
Sub-Saharan Africa	14,427	1,460	10
W. Asia/N. Africa	1,224	476	39
South and S.E. Asia	19,038	1,776	9
Latin America	23,807	3,884	16
Total	**58,496**	**7,596**	**13**

Note : Temperate zones excluded.

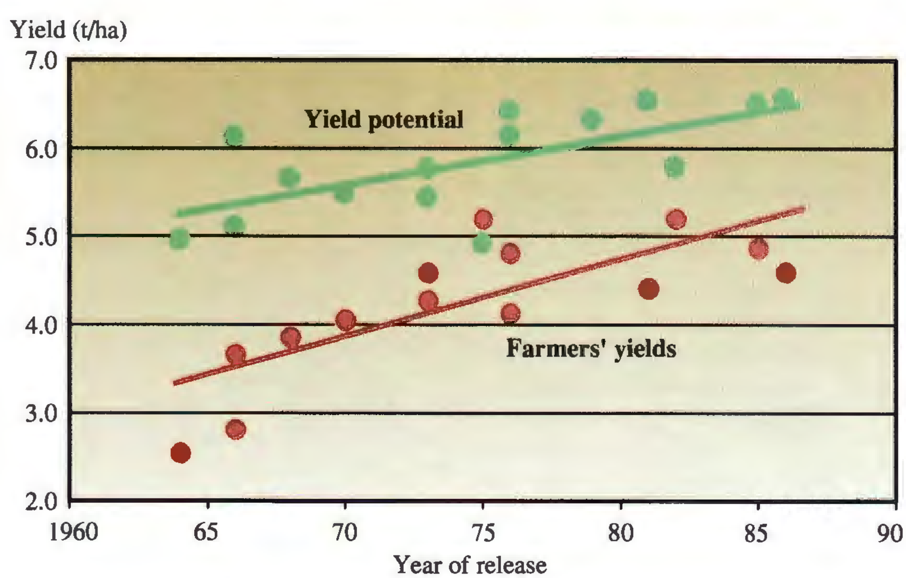


Figure 7. Yield gains in popular wheat varieties, 1964-86 (data from northwest Mexico).

potential, and for that reason has always received considerable attention by CIMMYT wheat researchers. The combination of better disease resistance and higher yield potential in the early semidwarfs contributed to their widespread adoption. Built-in protection against rust epidemics provided farmers with a kind of agricultural insurance, reducing the risk that they would lose their investments in the new seed and other inputs. More recently, CIMMYT researchers have been working on other diseases as well. It is too soon to assess the impact of these efforts, however; resistant materials are either still at the experimental stage or only now reaching farmers in varieties developed by national programs.

The conclusions drawn here have to do with the benefits of germplasm resistant to the rusts of wheat, particularly leaf rust, which is a severe and widespread hazard to the crop. Efforts to contain the threat have been complicated by rapid evolution of the pathogen, which greatly shortens the useful life of varieties with race-specific resistance. In the past, we focused on developing new generations of germplasm with different combinations of race-specific resistance genes, a task often referred to as "maintenance research" and one aimed at providing national programs and farmers with new sources of resistance to the mutating leaf rust pathogen.

The importance of such maintenance research can be clearly seen in Figure 8, a highly simplified representation of the benefits of this work. When the variety Siete Cerros was released in Mexico in 1966, it had a yield potential of about 6.1 t/ha and was resistant to the prevalent forms of leaf rust. Since then, its resistance has broken down and its ability to yield has declined. On the other hand, the recent variety Opata 85 is resistant to the leaf rust pathogens prevalent today and also has a higher genetic yield potential than Siete Cerros. By growing Opata 85 (and other new varieties), Mexican farmers gain in two ways: they avoid the yield losses inflicted on older varieties like Siete Cerros by evolving pathogens, and they enjoy the fruits of higher yield potential. It can also be argued that farmers in Mexico and elsewhere benefit from the positive contribution of genetic disease resistance to the health of the environment (see box, page 26).

We can estimate the benefits to developing country farmers of maintaining leaf rust resistance by projecting yield losses that would have occurred if resistant germplasm had not been available. Studies indicate that the disease can cause losses of 25-45% at specific sites during years when conditions are right for an epidemic

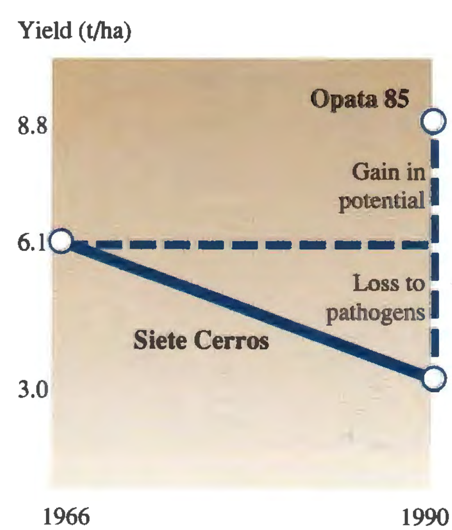


Figure 8. Schematic showing the effects of mutating pathogens and gains in yield potential over time.

Wheat Yield Gains in Marginal Environments

The benefits of the early Green Revolution wheat varieties, so obvious in favored environments, once eluded farmers living in marginal areas. Only with the development of hardier plant types (many from the spring x winter crossing program initiated by CIMMYT in the mid-1970s) did more suitable materials begin to make their way into those areas. There is now growing evidence that farmers in marginal areas, both in developing and developed countries, are beginning to reap their fair share of the benefits of improved wheat varieties.

In the drier areas of Pakistan, modern wheat cultivars have only recently offered farmers a sufficient yield advantage to compensate them for the lower price offered for grain produced by these varieties and for a perceived loss of straw. New materials, derived by combining spring and winter wheats, promise to alter this equation significantly (Ahmad et al.1991). It has been estimated that in mountainous areas the Veery-based variety Pak 81 gives farmers a yield gain of 35% over the tall local variety and nearly 15% over previously released semidwarfs. Elsewhere in the country, farm surveys have consistently shown that Pak 81 outperforms other semidwarfs by some 10 to 20%.

Notable progress has also been achieved in warmer regions, where conditions are generally far from ideal for wheat production. Results from trials conducted in Brazil and Paraguay indicate that gains in fairly warm, rainfed environments are on the order of those achieved in more favorable areas under irrigation. In Bangladesh the variety Kanchan, a cross made by Indian scientists using a CIMMYT parent line, consistently outyielded Sonalika, the variety most Bangladeshi farmers grow, by some 17% in 3,000 on-farm demonstrations over a five-year period.

And while CIMMYT does not work for developed countries, per se, further evidence of the improved hardiness of semidwarfs related to our work comes from Western Australia, where modest jumps in yield of 5 to 10% over the performance of local tall varieties are being obtained under that region's very harsh dryland conditions.

(Dubin and Torres 1981; Kohli 1985; Bajwa et al. 1986). Average losses in farmers' fields are much lower, ranging from 5 to 20% in favorable environments. If one assumes that average yield losses without resistant germplasm would be 10% and that the expected life of a variety is ten years, then the yield losses avoided through maintenance research would amount to at least 1% per year. In the developing world's favorable wheat areas alone, the annual value of this contribution would be some US$150 million at current prices.

While largely successful, the maintenance breeding approach left us on a kind of "wheat rust treadmill," racing to stay just ahead of evolving pathogens. In recent years, however, our fundamental resistance breeding strategy has changed. We now emphasize combinations of genes that provide "partial resistance" to leaf rust. While some rusting still occurs, the progress of the disease is slowed such that yield is largely unaffected. The really good news, however, is that this resistance has proven to be quite durable. Why this is the case is still something of a mystery, though some theorize that instead of trying to slam the door shut on the pathogen, as is the case with race-specific resistance, partial resistance enables a form of coexistence that reduces pressure on the organism to mutate into more virulent forms. For more on this, see Wheat Research, pages 35-39.

S. Pasten

Direct injection of individual plants with leaf rust inoculum is a painstaking and time-consuming process, but it gives wheat breeders the uniform disease pressure they need to evaluate resistance and, in the end, helps protect farmers from costly losses to the disease.

Maize

Achieving durable resistance to major diseases is less problematic in maize than in wheat, and many of CIMMYT's advanced materials have strong resistance to diseases prevalent in our target areas.

As for yield potential, we have less concrete data than for wheat. Even so, we are convinced that the modern maize varieties now being distributed in developing countries have considerably higher yield potential than do the local alternatives. Supporting evidence can be divided into two categories: data from on-farm trials managed by researchers and from experiments under farmers' management. The former are often conducted under different levels of fertilizer, including none or very little, the treatment that is most representative of conditions in farmers' fields. While the results of these studies are rather variable, reported yield gains are significant. In trials managed by farmers, yield gains tend to be smaller than those obtained in researcher-managed on-farm experiments. Commonly, improved varieties show a yield advantage of 5-15%, which approximates that of semidwarf wheats in rainfed environments.

Environmental Benefits of Improved Varieties

The now widespread adoption in developing countries of improved wheat cultivars and the rapidly growing use of improved maize varieties confers significant environmental benefits. One of the most important of these results from increased production per unit of land in favorable environments where agriculture is already practiced. Increased productivity there has reduced pressure on tropical forests and marginal lands that may be rapidly degraded when brought into production. In India, for example, farmers produced 48 million tons of wheat and rice on 54 million hectares during 1965. By 1990 they were able to grow more than two and a half times that amount on only about 25% more land. Think of the impact on India's forests and hillsides if farmers had to produce today's harvests with late 1960s yields! Much the same thing has happened in other developing countries where improved varieties are being widely used.

A second important environmental benefit of modern cultivars derives from their fortified genetic resistance to diseases and insects. CIMMYT maize and wheat researchers give considerable attention to building such resistance into the genetic makeup of improved materials — with marked success (see Maize and Wheat Research, pages 30-39). Their success helps poor farmers increase the stability of maize and wheat yields without resorting to potentially harmful chemical treatments, which they can ill afford and in fact rarely have to apply. The environment gains because fewer noxious chemicals are released into the biosphere.

Finally, because it severely limits the choices available to farmers and to others, poverty itself has been cited as a root cause of environmental degradation in developing countries. Thus to the extent that modern agricultural technologies can improve the welfare of poor producers and consumers, and at the same time provide farmers choices that favor environmental health and resource conservation, we will *all* benefit from the results of agricultural research.

The variability of yield data, combined with the difficulty of determining accurately the area planted to improved maize, points to the obvious need for additional analysis before average annual rates of gain in yield can be estimated with confidence. We believe that such an analysis will show significant yield gains over traditional varieties.

Another way of looking at the benefits from improved maize varieties, though, appears in a recent study on Latin America by a research team representing three CGIAR centers (Janssen et al. 1992). They estimate a production increase *for 1990 alone* of 1.7 million tons from the CIMMYT-derived varieties released in the region. The value added of this extra maize is calculated at about US$200 million, clearly a significant return on the research investment of CIMMYT and national programs.

Who Benefits?

As the Green Revolution gained momentum in the late 1960s, a vigorous debate ensued in which critics proclaimed that relatively well-to-do farmers received the lion's share of the benefits from semidwarf wheats. Subsequent research demonstrated that this was not the case (Lipton with Longhurst 1989). Although larger-scale farmers tended to adopt the new varieties first, small-scale producers joined soon afterwards. There were large discrepancies in the rates of adoption, but studies showed that they were related to agroclimatic and other differences among environments, not to farm size.

Even the large imbalance between optimum and less favorable environments seems to have diminished since the 1970s, as semidwarfs have slowly but steadily advanced into areas characterized by drought, soil problems, and other stresses. Nonetheless, adoption of these varieties is far from complete. In numerous places, including Ethiopia, dry areas of the WANA region and of central and southern India, and highland zones from Turkey to Afghanistan, farmers have yet to enjoy the benefits of wheat research. The difficult circumstances of these people call for a continuing commitment to the development of hardier genotypes and to improved management of crops and agricultural resources.

Even though adoption was slow in some areas, consumers across all environments benefitted tremendously from the spread of semidwarf wheats. India, for example, has remained roughly self-sufficient in wheat production, despite large increases in utilization. Real wheat prices paid to Indian farmers have fallen by more than 3% yearly since 1970, and prices paid by consumers have dropped at an annual rate of over 2% (Figure 9). This trend has helped the poor in particular, since they spend a sizeable proportion of their income on wheat products (about 20% in the Indian Punjab, for example). A similar situation has prevailed in Pakistan, though increases in real land prices there have enabled farmers to make up for some of the losses in real grain prices (Renkow 1991a). In smaller countries that import large quantities of wheat, producers (and in some cases, taxpayers) have probably been the major beneficiaries. Regardless of overall trends in producer

As of 1990, over 47 million hectares in developing countries were devoted to CIMMYT-related wheats, accounting for over 70% of total wheat area and about 80% of total production (not counting China).

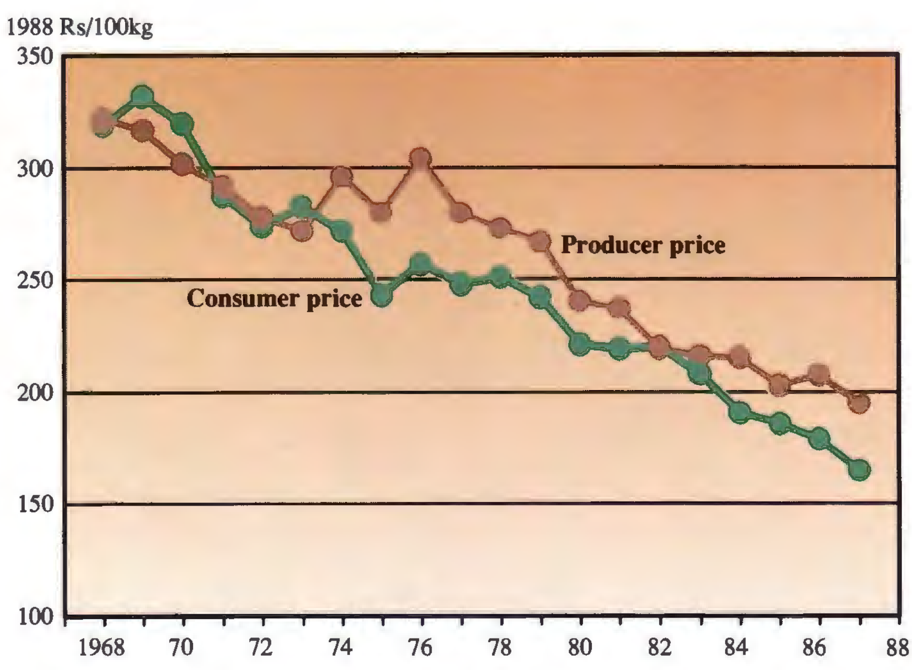


Figure 9. Trends in the price of wheat (Punjab, India).

and consumer prices, it is important to remember that many small-scale farmers must purchase wheat once their homegrown supplies have been exhausted. As net consumers of this commodity, farmers in any region, but particularly in the marginal environments, can capture some of the benefits generated by technological change in favored areas (Renkow 1991b).

We need to look beyond production and consumption, however, and view the consequences of technological change in a broader context. At root, improved technologies can be seen to have two major effects. One of these occurs via producers. More effective agricultural technologies increase the incomes of those who hold agricultural resources. That in turn leads to an increase in demand for goods and services, which increases the incomes of others and contributes to widening rounds of demand. In this way, agriculture serves as an engine of growth.

The second and more universal effect of technological change is made manifest through declining prices for basic foodstuffs, which have major implications for real wages, savings, investment, and overall economic growth. Indeed, throughout most of human history economic development has been associated with lower real food costs, which serve to expedite the development process.

Closing

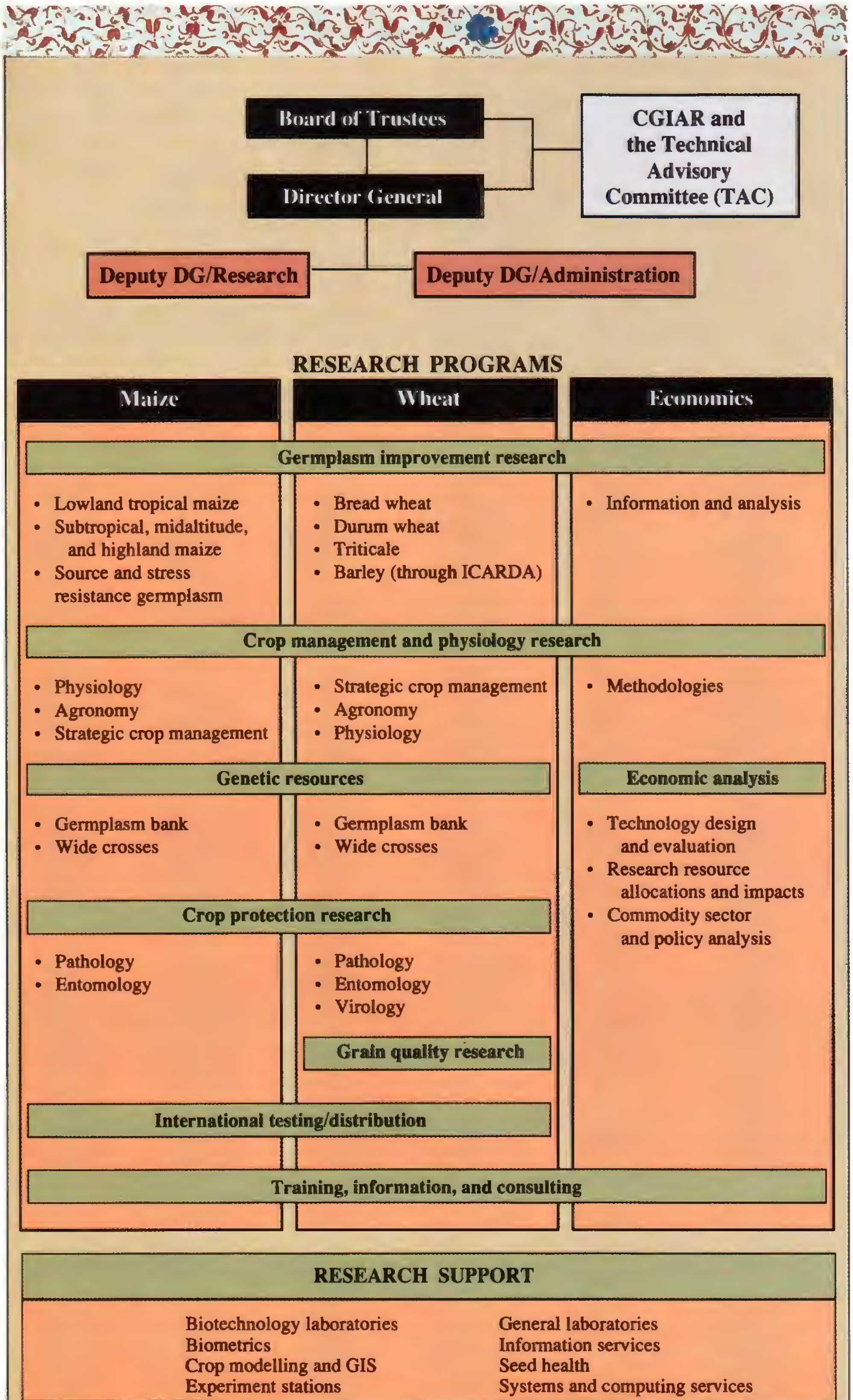
The foregoing clearly demonstrates some of the more important payoffs associated with maize and wheat research. It is worth emphasizing again that the returns to this work — judged to be extraordinarily large by those familiar with the effort — are the result of close collaboration with national programs throughout the developing world. Moreover, substantial benefits stemming from the use of new products only now becoming available to farmers will accrue in the near future. This is especially true in the case of maize.

Success, however, will depend on wider recognition of food as the means for dealing with the primary concerns of developing countries — the welfare of women and children, the environment, and population growth itself. Without abundant, low-cost food, progress in each of these realms is much more difficult; food remains the linchpin for progress. Developing countries must have productivity increasing maize and wheat technologies and will count on research to provide them. And CIMMYT, with its inspiring record and its proven capacity to adapt to new opportunities, will — in concert with national programs — continue to play a major role.

K. Elsesser

Having enough to eat can make the difference between living and merely subsisting. Effective agricultural research increases the chances that people will have enough food to thrive — not just survive.

Highlights of 1991 Activities



CIMMYT is organized to undertake a wide range of research and related activities aimed at providing national programs — and through them, farmers in developing countries — with ever more effective maize and wheat technologies (see diagram at left). The pages that follow give evidence of progress in selected areas.

Maize Research

K. Elsesser

Of all the cereals, maize has traveled farthest afield from its center of origin. The crop is grown from northern Asia to the Southern Cone of South America, from below sea level on the Caspian Plain to over 3,000 meters above in the Andean highlands. Not surprisingly, maize is cultivated in a multitude of ecologically diverse niches, exposing it to many biotic and abiotic hazards.

CIMMYT's maize improvement research was initially concentrated in Mexico, the crop's center of genetic diversity. Work there has allowed the Maize Program to endow its improved populations with resistance to some of the principal diseases of maize, such as the rusts and the leaf blights. The variety of environments in which maize is grown, however, has slowly led to a strategy of more decentralized research, with our scientists located in key maize producing regions and focusing on prevalent maize types or stresses. In the highlights that follow, we describe work on three such stresses — downy mildew in Asia, maize streak virus in Africa, and corn stunt in Central America. In addition to research concerning these regionally important diseases of maize, the reader will learn of our efforts to control other intractable parasites of the crop: insects of the moth group, which attack maize worldwide. It is hoped that by depicting the variety of organisms which derive sustenance at the expense of maize yields, these reports will also furnish an idea of the complexity of maize farming in developing countries and the challenges we face in providing superior germplasm.

Old Life Forms, Recent Foes: Downy Mildew and Maize

When European explorers reached the shores of Mesoamerica, the stage was set for an unprecedented blending of cultures and life forms from distinct hemispheres. Often the ensuing interactions have proven contentious. Such is the case between maize, an increasingly popular crop in the warm, humid climates of Asia, and downy mildew, a fungal pathogen native to the continent. With the rise of maize farming in the region, serious epidemics of the disease have been reported in India, Indonesia, the Philippines, and Thailand.

The Maize Program undertook breeding for resistance to downy mildew in 1975, establishing a regional program that built upon the pioneering efforts of agricultural research institutions in Thailand and a Rockefeller Foundation initiative, the Inter-Asian Corn Program (IACP). Over the years, Maize Program staff in Asia have worked closely with national programs, especially those of the Philippines and Thailand, shuttling promising germplasm back and forth between sites in Asia for screening under artificial infestation with the fungal pathogen. This approach was instrumental in the development of improved, downy mildew resistant maize now used region-wide.

Activities since then have included improvement of four broad based populations assembled in 1986 to provide clients with a range of grain color and maturity types in downy mildew resistant maize. Our progress with these materials was examined in a recent study by staff in Asia. Remnant seed from successive cycles of selection of each population was grown at sites in the Philippines and Thailand under both disease free conditions and disease pressure to measure improvement for agronomic traits and disease resistance. The data (Table 5) suggest that it is possible to make simultaneous progress on yield and resistance to downy mildew. In another useful result of the study, our breeders noted that improvement for downy mildew resistance can be hastened by selecting in the Philippines, where the fungal species is more virulent.

Much of the present work by our staff in the region is aimed at incorporating a range of useful traits, including downy mildew resistance, into improved germplasm for Asian environments. In conjunction with headquarters, for instance, they are working to improve resistance to downy mildew in CIMMYT tropical maize that already possesses acceptable resistance to multiple insect species.

In addition, we have received requests from Asian national programs for maize tolerant to the acid soils characteristic of nearly 300 million hectares in the region. To begin addressing this need, our staff have crossed sources of downy mildew resistance with acid soil tolerant maize developed by CIMMYT scientists in Colombia and will select progeny in trials under both acid soil and downy mildew stress.

Help for African Farmers: Resistance to Maize Streak Virus

Nearly unknown outside of Africa, maize streak virus is among the most serious disease problems of the crop on this continent. Its destructive potential was fully manifest during 1983 and 1984, when outbreaks seriously affected maize production in several countries of West Africa, and again in 1988 in a severe epidemic in Kenya. Despite this

Table 5. Progress in breeding for resistance to downy mildew in Thailand and the Philippines

Population	Cycle	Grain yield (kg/ha)	Disease score (% infection)
Early white	C0	5,171	59.7
	C3	6,110	24.4
Early yellow	C0	4,638	75.0
	C3	6,510	18.4
Late white	C0	5,770	63.8
	C3	6,724	16.9
Late yellow	C0	5,152	53.1
	C3	7,113	15.9

menacing power, the virus would be helpless were it not for leafhoppers, insects of the genus *Cicadulina* which transmit the pathogen while feeding on maize plants.

Practices such as timely planting and treatment of seed with systemic insecticides can help control yield losses, but a more effective and practical solution for subsistence farmers of streak-threatened regions is high yielding, disease resistant maize.

Advanced inbred lines now possess excellent resistance to maize streak virus . . . and combine well with hybrid materials used in most breeding programs of southern Africa.

From 1980 to 1988, CIMMYT pooled its efforts toward that end with those of the International Institute of Tropical Agriculture (IITA). Through resistance "conversion" of superior materials by backcrossing and recurrent selection in tropical populations, the CIMMYT/IITA team generated a sizeable collection of improved, streak resistant germplasm of lowland adaptation for use by national programs throughout sub-Saharan Africa (CIMMYT 1985).

We continued this work under a project launched in southern Africa in 1985. With support from the government and the University of Zimbabwe, CIMMYT established a research station near Harare to develop germplasm for eastern and southern Africa's midaltitude ecologies, which account for some 6 million hectares of maize production. Once primarily a concern of lowland farmers, maize streak virus is now a major constraint in midaltitude environments of Africa and has appeared lately even in highland fields. The station's facilities for mass rearing *Cicadulina* leafhoppers permit screening under maize streak virus pressure at all stages of germplasm development.

An innovative feature of this enterprise is the breeding methodology used. The central strategy of the Maize Program has involved improving a more or less fixed set of populations over a long period of time. Harare staff devised a new approach in which they continually created and screened new breeding populations drawn from large collections of elite germplasm, thereby heightening opportunities for tapping useful genetic diversity. National programs have played a vital role in the research, providing source germplasm and helping to screen materials under development. Progress in streak resistance has come rapidly; so much so that our researchers have also been able to concentrate on other important traits, such as yield and resistance to leaf blight and common rust, in the midaltitude materials. A regional testing network was started in 1989 for these products, and national programs in the region are using them extensively in their breeding activities. A list of the streak resistance germplasm we offer is now available to interested clients.

The above approach is presently giving way to a reduction in the volume of materials under development, as staff focus exclusively on the most elite midaltitude germplasm. From 36 populations at various stages of breeding in 1990, scientists have formed 6 broad-based, streak resistant groupings: 2 of intermediate maturity, 2 of late maturity (these first 4 of opposite heterotic groups), and 2 developed with drought tolerance in mind and also drawn from materials of diverse heterotic patterns. Advanced inbred lines from population ZM607, for example, possess excellent resistance to the virus, are high yielding and adapted to midaltitude conditions, and combine well with hybrid materials used in most breeding programs of southern Africa (where hybrids are traditionally preferred to open pollinated varieties). Work also continues to ensure that all CIMMYT lowland maize germplasm targeted for Africa features streak resistance among its qualities.

Teamwork in Central America and the Caribbean: Breeding to Avert Corn Stunt

For the past 14 years, the Swiss Development Corporation has funded joint research by CIMMYT and nine countries of Central America and the Caribbean. The project's contributions to maize research and productivity are well documented, including improved varieties, hybrids, and crop management practices, advances in seed production and distribution, and a strengthened capacity in national programs to conduct relevant research. One of its finest achievements, though, has been work on resistance to corn stunt, a serious constraint to maize production in some nations of the region.

Caused by micro-organisms akin to bacteria known as mollicutes, corn stunt can reduce yields by 60 to 100% in areas where low rainfall, high temperatures, and low relative humidity favor development of the leafhoppers that transmit the pathogen. Data from Nicaragua describe losses from corn stunt of as much as US$7.5 million in that country during the 1986-87 crop cycle.

CIMMYT began breeding for stunt resistance in 1975, collaborating with researchers from El Salvador and Nicaragua. By 1980 high yielding, stunt resistant varieties were released in several countries. One product of joint research with national programs, the variety NB-6 released in Nicaragua, gave yields of 3.5 t/ha in this country in 1987 under disease intensities that reduced the output of a susceptible hybrid to 1.5 t/ha. Figure 10 illustrates results of recent trials comparing the performance under disease attack of NB-6, the popular commercial hybrid H-5, and another maize genotype derived more recently from the project. Stunt resistant varieties and hybrids developed through our efforts with national programs are now sown on more than 100,000 ha throughout the region, practically eliminating the threat of the disease there. Project researchers nonetheless expect to advance both disease resistance and yield by some 10% over the next five years.

Developing and disseminating stunt resistant maize is not the only accomplishment of this work, though. Whereas project activities were first coordinated by CIMMYT staff, as of 1985 El Salvador and Nicaragua assumed leadership for breeding research on stunt resistance, with assistance on international aspects from our scientists. Products are shared among all nations participating in the project, and much of the joint research is organized and conducted by national programs themselves. The success of this approach has demonstrated the possibilities of a more dynamic role for national programs in shaping CIMMYT germplasm to regional requirements.

Moths That Eat Maize: Developing Resistance to Insect Pests

The number-one insect enemies of maize farmers are moth larvae known as "borers." True to their name, these insects voraciously chew their way through leaves, tassels, stems, and ears. If unchecked, their aggressive feeding habits leave behind a stunted, unproductive plant riddled with holes and tunnels. In developed world maize production, borer damage is held down through integrated pest management and insecticide use. Farmers in developing countries often lack access to similar controls or simply cannot afford them, and may lose a third or more of their harvest annually to borers and their leaf- and ear-feeding moth relatives, the armyworms and corn earworm. An obvious remedy is maize that can withstand or resist borer, armyworm, and earworm attacks.

Meaningful progress toward that goal at CIMMYT first came in the early 1980s. Maize Program scientists at that time implemented practical techniques for mass rearing insects and delivering them to maize in the experiment field, thereby creating the artificial infestations necessary to identify resistant plants. Along the way, our researchers devised some innovations now widely used in research on insect resistance. An example is the "bazooka," an insect applicator that allows an experienced worker to spread uniform batches of larvae on 1,500 plants per hour.

Innovation, though, was also required in our breeding philosophy. Up to this point, the focus had been to improve insect resistance in broadly adapted, general maize populations, an approach rewarded by slow gains. With the entomological underpinning in place, our staff put into practice a new strategy involving special purpose populations assembled and improved mainly for insect resistance; and to not just one, but multiple maize pests.

Efforts with the first such set of materials, multiple borer resistant (MBR) Population 590, have brought encouraging results. In multilocation testing during 1989-90 in Canada, Mexico, and the USA, experimental varieties developed from Population 590 showed yield reductions on the order of 10% under intense artificial infestation with each of four major insect pests. Satisfied for the moment with that level of resistance, we have recently begun work on other traits that should make Population 590 more useful to our clients. Foremost is improving its resistance to leaf blights and the rusts. Another goal is to be able to offer white grain maize with insect resistance. Breeding for these and other characteristics will be performed under heavy insect pressure to maintain or improve pest resistance.

Encouraged by progress with the first special purpose population, which comprises largely temperate and subtropical maize, we established a second, multiple insect resistant tropical (MIRT) Population 390, using materials adapted to the lowland tropics and including sources of resistance to maize streak virus and downy mildew. Population development involved selection at our primary tropical

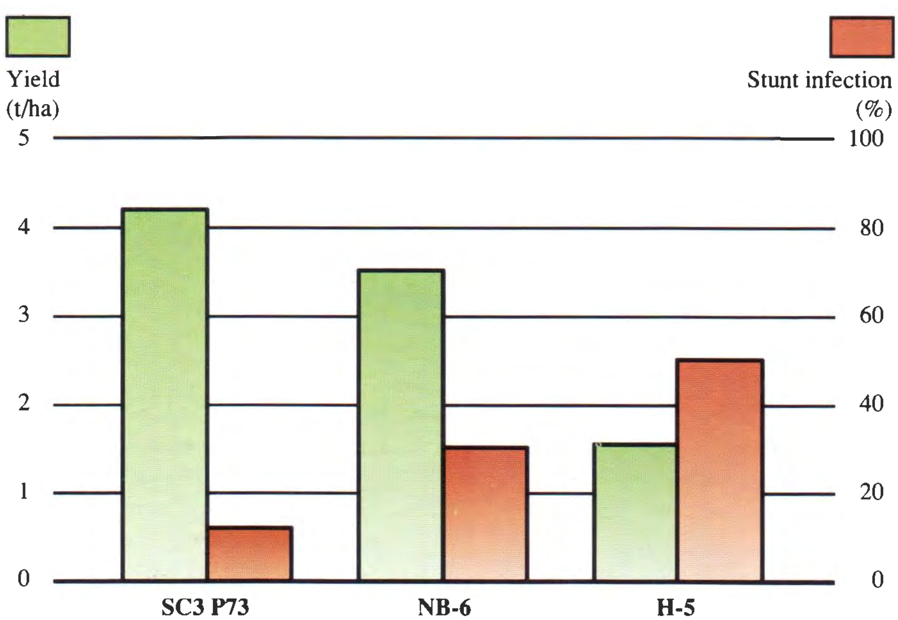


Figure 10. Means of results from recent trials under natural incidence of corn stunt at seven sites in Central America. The materials compared include a synthetic (SC3 P73) and Nicaraguan variety (NB-6) developed under the Central America and Caribbean collaborative project and a popular commercial hybrid (H-5).

experiment station in Mexico, where disease pressure is heavy. In preliminary results of 1990-91 international trials, several lines from Population 390 appear to possess both high levels of resistance to the major tropical borers and armyworms, along with acceptable resistance to maize streak virus, a critical pathogen of the crop in Africa. The next challenge is to increase yield potential in the population and improve resistance to other important diseases, such as downy mildew.

Future research will also focus on the factors and genetic control of insect resistance in CIMMYT materials. We have generally pursued "antibiosis," i.e. any plant factor (toxic substances, nutrient imbalances, or tough plant tissue) that kills the larvae or impedes development in survivors. We are beginning collaborative work with scientists in Canada to obtain basic information about the factors involved, in hopes of breeding resistant maize more efficiently and making better use of the final product.

With the same goal in mind, CIMMYT is well along in studies using restriction fragment length polymorphisms (RFLPs), molecular markers that can help locate areas on the genome that are associated with resistance. As part of our contribution to the European research network, EUREKA, our scientists have already employed 25 RFLP probes to analyze a segregating population developed from susceptible and resistant parents. These and previous studies signal some 11 areas on the genome as ostensibly responsible for resistance in CIMMYT materials to southwestern corn borer, one of the most aggressive feeders on maize. Research will continue until we have utilized at least 100 probes, providing a clear notion of the number and location of resistance genes. We hope eventually to be able to preselect for resistance using DNA markers, thus permitting more efficient and effective selection for a variety of traits under artificial infestations.

Another issue to which CIMMYT scientists are turning their attention is second generation borer attacks. As a rule, the first generation of larvae in the crop cycle begin feeding in the whorl of the maize plant, later assaulting the tassel and eventually penetrating the stem, where they pupate. The female adults of this brood lay their eggs on the tissue near the ear zone of the growing maize plant. Second generation hatchlings launch their attack on the sheath, collar, or husk leaves and later chew into the ear or stalk, where they tunnel extensively. Damage often causes the plants to break off at the stem and, at the very least, facilitates the entry of pathogens which further reduce yield and can contaminate the grain.

The complexity and labor requirements of screening for second brood resistance have led us to concentrate initially on leaf feeding resistance, an effective defense inasmuch as it reduces the number of second generation pests. First generation moths, though, may come in from neighboring fields of maize or other hosts and lay eggs on plants at flowering. To begin dealing with this problem, our staff will undertake comparative studies on screening methods involving second generation borers.

Finally, given that developing world maize ecologies are intricate systems that present an array of opportunistic organisms, our research has not confined itself to pests from the moth group. We can also offer germplasm with acceptable levels of resistance to maize grain weevil (*Sitophilus* spp.) and corn rootworm, and are collaborating with scientists from Texas and Colorado to improve CIMMYT maize for resistance to spider mites.

S. Pasten

Stem borers (like this larva) belong to the Lepidoptera, an insect order whose species comprise fully 10% of those known in the animal kingdom. Most are green leaf feeders and can thus pose a serious threat to agriculture.

Wheat Research

J.L. Castillo

High yield potential and host plant resistance to biotic stresses in CIMMYT's wheat germplasm have contributed much to the abilities of farmers in developing countries to improve and sustain their productivity. Disease and insect resistance have been as important as yield potential in determining the impact of our germplasm in the developing world.

In 1991, there were a number of significant developments involving some old biotic enemies and a few new ones. Reason enough to devote this year's highlights to our past and present work with biotic stresses. Nearly 80 projects involving more than a dozen diseases and pests (Fischer and Hettel 1991) are currently underway within our crop protection subprogram. Host plant resistance is our major armament in integrated pest management because it stabilizes yield for many small, poor farmers. In those few circumstances where developing country farmers use pesticides, disease-resistant germplasm obviates the need for their use, thus reducing environmental pollution.

Seeking Resistance to Russian Wheat Aphid

Historically, we have not worried much about insects in wheat. Many of the major pests (e.g., Hessian fly, sawfly) are found in West Asia and North Africa, and our sister center, the International Center for Agricultural Research in the Dry Areas (ICARDA), has been giving attention to these. But now, a small, pale green menace has suddenly added to the headaches of wheat and barley farmers in several developing and developed countries around the globe. The Russian wheat aphid (RWA), *Diuraphis noxia*, from Asia Minor is finding its way into new areas at an alarming rate. Finding host-plant resistance in the accessions of germplasm banks at CIMMYT and other institutions may be the only practical way to stop this voracious insect's onward march (Burnett et al. 1991). The aphids feed — and do their damage — deep within a plant's leaf whorl where the leaves are tightly rolled, which makes it difficult for natural predators or contact insecticides to reach them.

Originally recorded in 1900 in the southern Soviet Union and in Spain in 1945, RWA did not reach pest status anywhere until 1978 when it was identified as the causal agent of a wheat leaf streak in South Africa. Since then, the pest has spread to the Americas and has been recorded in most countries bordering the Mediterranean, Ethiopia, the Middle East, Pakistan, and Afghanistan. It has the uncanny ability to colonize environments very different from its center of origin — it can survive a winter in western Canada and a summer in Yemen and seems to thrive best in dry environments.

With the search for RWA resistance underway, our breeders are tapping into the vast genetic variability available in the thousands of small grain accessions stored in our wheat germplasm bank. We have screened several thousand spring wheats, triticales, ryes, barleys, and wild relatives of wheat for resistance. Triticale and rye genotypes in the CIMMYT collection and barleys from the ICARDA/CIMMYT program have been identified as having useful levels of resistance to RWA under field conditions.

Although there are many apparent sources of RWA resistance in our bank's tetraploid *Triticum dicoccum* accessions (wild wheats), we have so far found only a small number of resistant lines among the wheats themselves, most of which can be traced to the geographic origins of the aphid itself — southern Russia, Iran, and Turkey. These resistances and those from winter wheat genotypes selected elsewhere are now being incorporated into the CIMMYT spring wheat germplasm. Our wide cross researchers are working on the introgression of resistance from the wild species. Such transferred resistance will help avert disasters in countries where the RWA has been identified as a pest and perhaps prevent the aphid from ever reaching pest status in countries where it has yet to be recorded (Hughes and Maywald 1990).

Durable Rust Resistance in CIMMYT Germplasm

As described in CIMMYT's new manual on *The Rust Diseases of Wheat* (Roelfs et al. 1992), the three rust diseases (leaf, stem, and stripe) have plagued wheat farmers over the centuries and are still considered diseases of major significance where wheat is grown. In the past, rust resistance in improved wheat cultivars was commonly based solely on major, race-specific genes that often succumbed to mutant virulent strains within five to seven years. However, since the early 1970s, our breeders have been emphasizing what is called a "slow-rusting" type of resistance that usually thwarts the development of new pathogen races and slows down inoculum build-up of the pathogen. Slow rusting occurs when a cultivar displays a susceptible response, but with slower disease progress than in a susceptible check cultivar. The effectiveness of this slow rusting can be enhanced by identifying other genes influencing the phenomenon. For example, leaf rust resistance gene *Lr34* alone in a cultivar will cause slow rusting, as will gene *Sr2* for stem rust. However, by combining two or three additive genes (that also convey slow rusting) with *Lr34* or *Sr2* for the respective diseases, a durable resistance (lasting many years) of high effectiveness can be obtained where disease progress is retarded to the extent that pathogen development by harvest is negligible.

Thanks to such durable resistance, the threat of stem rust (*Puccina graminis*) has been contained globally for the last 30 years by the *Sr2* gene complex. Similarly, no major epidemics of leaf rust (*P. recondita*) or stripe rust (*P. striiformis*) have been reported for the last 11 years on CIMMYT-derived cultivars identified to have slow rusting.

Even though our breeders have achieved much regarding durable resistance, we must continue efforts to maintain and improve resistance levels to avoid a resurgence of the diseases. CIMMYT wheat pathologists and geneticists are identifying and classifying durable resistance genes, which will help our breeders in their maintenance and improvement efforts.

Leaf rust is the most widespread disease affecting spring bread wheat production and is particularly prevalent in irrigated areas. On the experiment station at Ciudad Obregón in Mexico's Yaqui

Valley, we compared 16 CIMMYT-derived bread wheat cultivars — with release dates spanning 24 years — from Sonora 64 to Angostura 88. The cultivars were grown under heavy leaf rust infection, both with and without fungicide treatment. We found that, in the absence of chemical control, cultivars released before 1973, such as Sonalika, Inia 66, and Yecora 70 (resistance attributed to race-specific genes at the time of release, but susceptible now), suffered losses of nearly 50% compared with virtually none for more recent cultivars, such as CIANO 79, Oasis 86, and Angostura 88 (resistance based on effective race-specific genes that may succumb to new pathogen races in the future). Interestingly, cultivars determined to be partially resistant (slow rusters), such as Cocoraque 75, Pavon 76, and Opata 85, yielded almost as well as the resistant cultivars (Sayre et al. 1991).

Using this same set of historical cultivars, we determined that the overall annual average gain over the last three decades through breeding for both yield potential and leaf rust resistance was 2.9%. When the cultivars were treated with fungicide, we observed a 1% average annual rate of gain in yield potential over the years. Obviously, leaf rust resistance accounts for the remaining — some two-thirds — of the overall gains (Figure 11). In terms of impact, had this bread wheat germplasm not been available over the years to national programs, we estimate that, on average, at least 5% of the developing world's wheat crop in areas where leaf rust is a factor would have been lost due to effects of the disease alone — a total of 5 million tons annually or some US$750 million each year at today's prices.

In many developing countries, stripe rust presents the greatest potential threat to spring bread wheat production. To get an historical perspective of our battle with *P. striiformis*, our breeders computed the percentage of CIMMYT advanced lines expressing resistance (an average coefficient of infection, ACI, of 5 or less as recorded by cooperators and unlikely to cause yield loss) over more than 20 years of the International Bread Wheat Screening Nursery (IBWSN). This information reveals that, until the mid-1970s, resistance to the disease in our germplasm was low. Then the first advanced lines involving genes introgressed from the winter wheat gene pool were sent to our cooperators. Quite rapidly, resistance increased as we moved into the early 1980s. Then a period of instability ensued that we attribute to resistance gene *Yr9* being effective in Mexico, but ineffective in certain other parts of the world. By the mid-1980s resistance was high again (van Ginkel and Rajaram, 1992).

While the instability has been obvious, the proportion of lines expressing high levels of resistance has remained above 20%. The mean annual rate of increase has been 2.4%. We are optimistic that the base of general stripe rust resistance can be further strengthened by accumulating durable resistance genes from different sources dispersed throughout our program and other known sources. Our work with stripe rust also currently involves a five-year Dutch-funded collaborative project with the Wageningen Agricultural University in the Netherlands to identify, characterize, and evaluate durable resistance to the disease.

To date, some 128 resistance genes have been identified by wheat pathologists and geneticists worldwide — 62 for stem rust, 44 for leaf rust, and 22 for stripe rust (Roelfs et al. 1992). Most of these, so far, have been found within wheat itself, but 32 (20 for stem rust and 12 for leaf rust) are derived from near and distant relatives of wheat like *Triticum turgidum*, *T. monococcum*, and *Agropyron elongatum* (Skovmand and Rajaram 1990).

Since many of the known genes are race-specific and have been rendered ineffective by new virulences, the search continues for more genes to add to the diversity of the resistance base in the wheat genepool — like stripe rust resistance gene *Yr18* identified by our own geneticists in 1991. The discovery of *Yr18* hinged partly on the use of two near-isogenic lines (i.e., nearly identical genetically), Jupateco 73R and Jupateco 73S. These two lines are reselections from the cultivar Jupateco 73 and were selected for leaf rust resistance based on gene *Lr34* (Jupateco 73R) and leaf rust susceptibility (Jupateco 73S). When tested for stripe rust in the field, Jupateco 73R was found to be always resistant to stripe rust while Jupateco 73S was always susceptible. Using genetic studies and testing other

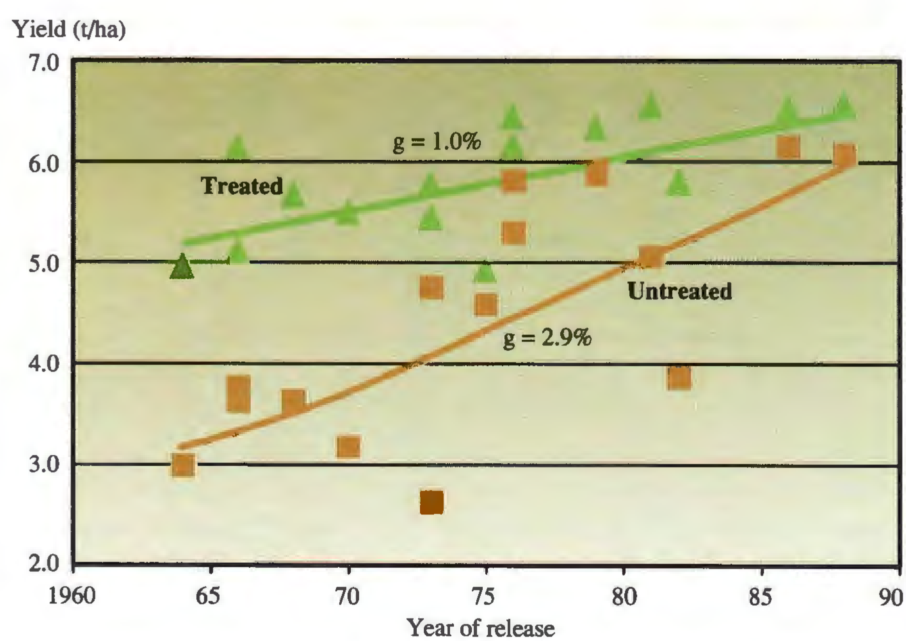


Figure 11. Yield of CIMMYT-derived varieties, with and without fungicide

cultivars that carry *Lr34*, we were able to conclude that *Lr34* is linked to a gene conferring durable resistance to stripe rust, which we named *Yr18* (Singh 1992a).

It is not uncommon for there to be genetic association among various resistance genes of the three rusts. However, the *Lr34*:*Yr18* linkage is significant because *Lr34*, derived from the leaf rust-resistant cultivar Frontana from Brazil, is an important gene known to impart durable resistance to leaf rust and was confirmed in 1991 to be present in a considerable number of wheats developed by CIMMYT breeders and is probably present in many other wheats. The *Lr34*:*Yr18* association provides a great advantage to breeders because when they confirm the presence of *Lr34* in a genotype, it automatically means a considerable degree of stripe rust resistance is also present through *Yr18*.

Rust resistance genes can also have genetic association with phenotypic or visual traits. For example, durable stem rust resistance gene *Sr2* has long been known to be linked with the presence of brown necrosis or pseudo black chaff. Recently, Canadian researchers indicated that *Lr34* might be linked to leaf tip necrosis in adult wheat plants. Again using the Jupateco 73 reselections in segregation tests in the field, our geneticists, in 1991, confirmed this observation (Singh 1992b) and used it to show the presence of *Lr34* in at least 31 CIMMYT-derived wheats that were thought to carry the important gene. Even though leaf tip necrosis may not be an attractive trait, CIMMYT-derived wheats with very high yield potential carry the leaf tip necrosis gene, which we have named *Ltn*. Now breeders have a visible marker to confirm the presence of both durable leaf and stripe rust resistance, knowing that *Lr34* is present as is *Yr18* by its linkage to *Lr34*. This tale of genetic association may not end here, which will become apparent in the discussion on barley yellow dwarf below.

> In 1991, CIMMYT researchers identified the first gene — designated *Bdv1* — for barley yellow dwarf tolerance in bread wheat. It is believed to be a source of durable tolerance to this ubiquitous viral disease.

A Gene for Tolerance to Barley Yellow Dwarf in Bread Wheat

Incorporation of tolerance to barley yellow dwarf (BYD) has been an objective of our breeders because the disease is the most economically important and widespread virus disease of small grains in the world (Burnett 1990). Losses range from 1 to 3% annually, although in some years and locations, losses may be as high as 20-30%. Since 1984, our work on BYD has been a restricted core project funded by the Republic of Italy, involving collaboration with a network of centers of excellence including various Italian and U.S. universities, the Ministry of Agriculture, Fisheries, and Food (MAFF) in Great Britain, Agriculture Canada, and institutions in some developing countries.

The luteoviruses, known as barley yellow dwarf viruses (BYDVs), are persistently transmitted by a variety of aphids to all common small grain cereals. The presence of BYD can be masked either by abiotic stresses, such as nitrogen deficiency and water-logging, or by other diseases such as the rusts or foliar blights. However, the effects of BYD are becoming more obvious in the field as more resistances to the foliar diseases are incorporated into wheat germplasm.

Several BYD-tolerant CIMMYT bread wheats have been available, but until 1991, we still did not grasp the genetics of tolerance in these wheats. Single genes, *Yd1* and *Yd2*, conferring tolerance to BYD are known to occur in barley, but only after crossing tolerant (Anza and high yielding CIMMYT advanced lines) and susceptible (Bobwhite and Bagula) parents, have we been able to identify the first BYD tolerance gene in bread wheat. We have designated this gene *Bdv1*).

Bdv1 could have been introduced into the CIMMYT germplasm from the BYD-tolerant cultivar Frontana from Brazil, which was used in the Mexican-Rockefeller wheat breeding program during the 1940s and 1950s for its outstanding resistance to rusts (which we today recognize as durable). For more than 40 years CIMMYT breeders and their predecessors have been discarding plants showing excess yellowing at our Toluca Station near Mexico City. Because of this heavy selection pressure for such a long period, we believe that *Bdv1* now occurs frequently in CIMMYT wheats. It could be classified as a durable tolerance source because it has maintained partial effectiveness despite large-scale deployment in the U.S. and other countries and confers tolerance to all known serotypes of BYDV. Since leaf rust gene *Lr34* is also derived from Frontana, we will be looking at the intriguing possibility that *Bdv1*, like *Yr18*, is genetically linked to *Lr34*. If so, leaf tip necrosis becomes an even more important phenotypic marker for breeders.

Gaining Disease Resistance from Alien Sources

An excellent example of acquiring disease resistance from a distant relative of wheat (by way of intergeneric crosses) is that recently obtained for spot blotch (*Helminthosporium sativum* syn. *Cochliobolus sativus*). Our wide cross researchers have obtained encouraging results crossing the wild grass *Thinopyrum* (*Agropyron*) *curvifolium* with three blotch-susceptible bread wheats. Spot blotch is an important disease that limits wheat production in many nontraditional warm areas, such as Paraguay, parts of Brazil, Bangladesh, the tarai of India and Nepal, and other tropical countries (Hetzler et al. 1991). Five years ago, nearly all wheat planted at our tropical lowland station in Poza Rica, Mexico (a hot spot for *H. sativum*) succumbed to the disease. Now however, advanced derivatives from the wide cross remain lush and green while susceptible wheats in adjacent plots turn brown and die.

The best resistance to *H. sativum* found to date anywhere comes from these *Th. curvifolium*-derived lines. The resistant selections have good agronomic types, variable maturity, and satisfactory grain finish. Yields of this material in the hot, humid Poza Rica environment are approaching 3.0 t/ha without fungicide, whereas susceptible wheats yield nothing. These selections are being incorporated into our mainstream breeding program and distributed to countries where *H. sativum* is a constraint, such as Nepal. The material is performing well in field tests there. In an attempt to widen the diversity of *H. sativum* resistance, we have also crossed some resistant synthetic wheats (durum wheat x *Triticum tauschii*) with susceptible bread wheats. Some selections from the early segregating populations of this interspecific work look promising.

Other Biotic Nemeses

Neither a disease nor an insect, the lesion nematode (*Pratylechus thornei*) is a tiny worm reported to parasitize wheat roots in Australia, the Middle East, North Africa, the United States, and Mexico. We are trying to determine the extent it affects wheat productivity. In a diagnostic survey conducted by our agronomists of 52 randomly selected farms in the Yaqui Valley of northwestern Mexico, nematode populations were shown to negatively correlate with wheat yields and to contribute to an overall model describing yield for the Valley (Meisner et al. 1992). The survey results demonstrate the need for more research into nematode populations in the Yaqui Valley and the effects of crop rotations on these populations.

Karnal bunt (KB) is a seedborne disease caused by the fungus *Tilletia indica*. Its severity is usually low to moderate in India, Pakistan, Nepal, and Mexico. However, it is a quarantinable disease that can seriously affect germplasm movement globally as well as within our breeding program in Mexico. We have identified numerous resistant lines in bread wheat, durum wheat, and triticale in the Karnal Bunt Screening Nursery, which we are sharing with collaborators in KB hot spots. In addition, our wide cross researchers are developing resistant material derived from *Triticum tauschii*.

Our research on bacteria, supported by the Belgian Administration for Development Cooperation, is aimed primarily at bacterial leaf streak (*Xanthomonas campestris* pv. *undulosa*). This disease is increasingly affecting bread wheat, durum wheat, and triticale grown in high rainfall, warm environments. In 1991, we developed and refined new foliar disease scoring scales for the three crops and made progress in finding resistance in CIMMYT germplasm.

Finally, our collaborative work with the fungus *Septoria tritici* has been producing good results. Those interested in more details should see our annual report for 1990 (CIMMYT 1991).

G. Hettel

Brown and dying wheat susceptible to helminthosporium spot blotch — an important disease limiting wheat production in warmer areas — is surrounded by lush, resistant lines descended from a wide cross with *Thinopyrum (Agropyron) curvifolium*, a wild distant relative of wheat.

Economics Research

T. Luba

What are the benefits of new technology? How can they be measured? How are they distributed? These questions conceal a host of issues, some of them quite complex, explored in studies ranging from an ambitious analysis of the impacts of maize and wheat research in the developing world to more specific investigations of technology adoption and returns to research.

Our study of global research impacts, conducted in collaboration with the Maize and Wheat Programs, began with a questionnaire soliciting information to develop a compendium of the number of maize and wheat varieties released by national programs. To extend the evaluation of impacts beyond previous analyses, we requested information about the type and germplasm source of those varieties, the agroclimatic zone(s) for which they were targeted, and the approximate area planted to them in 1990. Our survey included all countries harvesting more than 100,000 ha of maize and/or wheat, as well as many countries with smaller areas, to develop a comprehensive database on the use of CIMMYT germplasm in national programs and on farmers' adoption of varieties based on CIMMYT germplasm and other materials.

The resulting impact study reflects the contributions of CIMMYT's Maize and Wheat Programs, hundreds of national program researchers, and some private companies. Although our information on germplasm utilization is fairly complete, more precise information on the economic benefits attributable to the dissemination of improved maize and wheat awaits additional data and more extensive analysis. However, some results of this work are available in this report (see pages 16-28), and more detailed analyses will become available in two publications later this year.

Adoption Studies and the Impact of OFR

The broad picture of research impacts acquires greater depth when complemented by information from adoption studies. By indicating whether or not research objectives mesh with farmers' needs, adoption studies provide information for redirecting research, if necessary. They may also reveal institutional conditions, such as input supply policies, that affect farmers' ability to take up new practices.

Unfortunately, the small number of well-documented cases in which on-farm research (OFR) has fostered positive change in farmers' practices has made it difficult to judge the success of this kind of research. A new book, *Planned Change in Farming Systems* (Tripp 1991), brings together nine case studies of demonstrably successful OFR conducted by a variety of organizations on different agricultural systems in developing countries. The studies — four of which involved CIMMYT research — provide a concise review of progress in OFR to date, serving as a guide to conditions that contribute to effective OFR.

One chapter highlights work in which CIMMYT participates in Ghana. The Ghana Grains Development Project (GGDP), a national commodity research program, has used the OFR methodology to generate widely applicable recommendations for Ghana's major maize producing environments. Following up on adoption information gathered in the course of the research described in the case study, a 1990 survey showed that Ghana's maize farmers — women as well as men — are increasingly familiar with the recommendations and use them in their fields. About 48% of the maize area covered in the survey was planted in improved varieties released by Ghana's Crops Research Institute. However, the level of success achieved through OFR in Ghana has not been equalled in many other places. This fact points to the need for more documentation of the impact of OFR — and hence more accountability to farmers and to funding agencies — so that the efficiency of OFR can be assessed and improved.

Research in Natural Resource Management

Adoption studies are all too often thought of as the "last word" in the research process. This perception is not quite accurate. As research proceeds, adoption studies help monitor progress, synthesize accomplishments, and highlight future challenges. And in 1991, the Economics Program initiated two adoption studies that can be thought of as a prologue to research — certainly not an afterword.

These studies are being done with the assistance of national programs and non-governmental organizations in two locations that share an unusual characteristic: poor smallholders have adopted resource-conserving technologies that are not part of the traditional system. In both places most farmers grow maize on steep hills susceptible to erosion. Farmers in a small area of western El Salvador have practiced conservation tillage for 10-15 years. Along the Atlantic coast of Honduras, farmers follow a maize-Mucuna rotation. (Mucuna, or velvet bean, is a leafy, rapidly growing leguminous plant that not only provides nitrogen to the soil, but also helps control erosion, preserve soil moisture, and discourage weeds.) The studies in El Salvador and Honduras will elicit farmers' perceptions about resource-conserving technologies and reveal the technical and institutional factors which shape those attitudes. That information will be valuable in designing OFR specifically directed toward improving natural resource management in smallholders' farming systems.

On-farm research is already being done to understand and evaluate practices used for natural resource management in southern Veracruz, Mexico. Like their counterparts in Honduras, the indigenous farmers living near the Santa Marta Mountains have developed a maize-Mucuna system without technical assistance. Mucuna is sown on fallow fields to improve soil fertility and inhibit the growth of tough grass that farmers usually clear by slashing and burning. A typical fallow plot can take one person 12 days to clear, compared to four days for a fallow plot the same size but sown to Mucuna.

In addition, some farmers use Mucuna to produce two maize crops instead of one. In October or November, farmers clear the Mucuna fallow and plant maize. The cut Mucuna is used as mulch for the emerging maize crop, adding nutrients and holding moisture in the soil during the relatively dry winter months. Farmers also sometimes grow maize and Mucuna together during the rainy summer cycle, a practice which may become more important as the amount of fallow land diminishes and recuperative fallow cycles become shorter.

This and other information on farmers' use of Mucuna was used to design on-farm experiments to assess the agroeconomic limitations and advantages of the Mucuna practices and to encourage farmers' experimentation. Results of this work, which should be available in 1992, will be linked with the research in Honduras.

Obviously, OFR on natural resource management in smallholder maize farming systems of Mexico and Central America must consider longer term effects, such as changes in the amounts of soil nutrients or in soil erosion. This challenge is not unique to Latin America. For example, OFR conducted by the University of Southern Mindanao Agricultural Research Center, Philippines, in collaboration with CIMMYT highlights the need to account for longer term effects resulting from the use of different weed control strategies in maize. The choice of weed control practice not only influences weed species and populations over time; it may also influence rates of soil nutrient depletion, soil erosion or conservation, and the incidence of diseases or insects. Researchers have realized that, without better information gathered over a longer period, they cannot quantify the carryover effects of weed control strategies with sufficient precision. Depending on the particular strategy that is being studied, different data collection methods are needed, including long-term trials (some managed by farmers, other by researchers) and long-term monitoring of farmer groups.

The work described above shows how researchers' repertoire of methods is expanding to meet the demands of research aimed at enhancing or maintaining the productivity of agricultural resources. The Economics Program is developing guidelines for *ex-ante* evaluations of resource-conserving technologies and for improving farmers' involvement in research on such technologies. In addition, we are examining methods for the economic analysis of experimental data encompassing effects over several years.

Farmers' Adoption of Maize in Malawi and Durum Wheat in Ethiopia

For the farmers who have adopted them, the conservation tillage and maize-Mucuna technologies in Central America obviously offer specific advantages, which researchers seek to understand through farmer interviews. The same technique helped researchers to unravel farmers' various motives for producing different types of maize in Malawi and to document farmers' criteria for adopting different varieties of durum wheat in Ethiopia.

Malawi is described as "a nation of maize farmers" because more than 75% of its cropped area is sown to maize. But it might be more to the point to call Malawi a "nation of maize consumers." Malawi's per capita maize consumption is among the highest in the world. Moreover, farmers' acceptance of improved maize varieties available in Malawi is conditioned by consumption preferences related to the way that flinty maize varieties are traditionally stored and processed.

National program and CIMMYT staff have documented the adoption of different maize types (local maize, open-pollinated varieties, and hybrids) and fertilizer use, and they have analyzed factors affecting farmers' demand for flint maize varieties compared to dent maize. Consumption preferences *alone* do not dictate which maize technology farmers choose, since farmers seek to attain a variety of objectives under a variety of constraints. But even farmers who adopt improved maize technology on some of their land still sow flinty local varieties to meet their requirements for food and satisfy strong consumption preferences. This information points to the need for developing a more flexible approach to promoting the adoption of improved maize in Malawi, through policies that

T. Luba

A farmer (right) tells an Ethiopian researcher why he grows an improved durum, Boohai. "These farmer surveys are very important," the researcher later observed, "because we serve the people — we have to understand *their* needs."

are more attuned to farmers' reasons for using both local and hybrid maize as well as different levels of inputs on each.

Near Debre Zeit, Ethiopia, about 150 farmers in three durum wheat producing areas participated in a survey designed to document which durum varieties farmers grew and why. One curious finding of the study was that two of the "durum" wheat varieties identified by farmers are actually improved bread wheat varieties that meet some of farmers' standards for good durum wheat, such as large amber grains and early maturity. Given that improved durum wheats were introduced in the survey areas over 20 years ago, it was not surprising that only 6% of the farmers surveyed still grew local unimproved durum varieties. (Elsewhere in Ethiopia, local durum cultivars predominate.) The survey confirms that several durum wheat characteristics valued by farmers are already being incorporated into improved durums by Ethiopian breeders but also reveals additional characteristics which breeders may wish to emphasize.

The Economics of QPM for Animal Feed

Several countries have developed open pollinated maize varieties and hybrids based on quality protein maize (QPM) germplasm from CIMMYT. Although QPM was promoted as a source of protein in food for human consumption, for a number of reasons QPM has yet to be adopted widely for that purpose. The potential uses of QPM for animal feed have received little attention, however, and in 1990 the Economics Program initiated a study in Brazil and El Salvador to examine the economics of QPM as feed for pigs and chickens. These two countries offered contrasting settings for the study: the Brazilian pig and poultry industries are large and sophisticated, and most ingredients for animal rations are produced domestically; the Salvadoran pig and poultry industries are still developing, and El Salvador imports many of the ingredients required for animal feed. These differences apart, both Brazil and El Salvador have strong seed industries, and the production and distribution of QPM seed in either country does not pose a problem.

In both countries, QPM shows greater potential as a substitute for normal maize in pig rations than in chicken feed (Figure 12). Quality protein maize can constitute 80% of the optimal pig feed, replacing all of the normal maize, synthetic lysine, and 40% of the soybean meal. Including QPM in feed could reduce the cost of producing pig and chicken feed in each country (Figure 13), but these savings are significant only as long as the price of QPM is the same as that of regular maize.

Given that the Salvadoran feed industry is still developing, QPM may have more potential among small-scale farmers as feed for their own animals than among

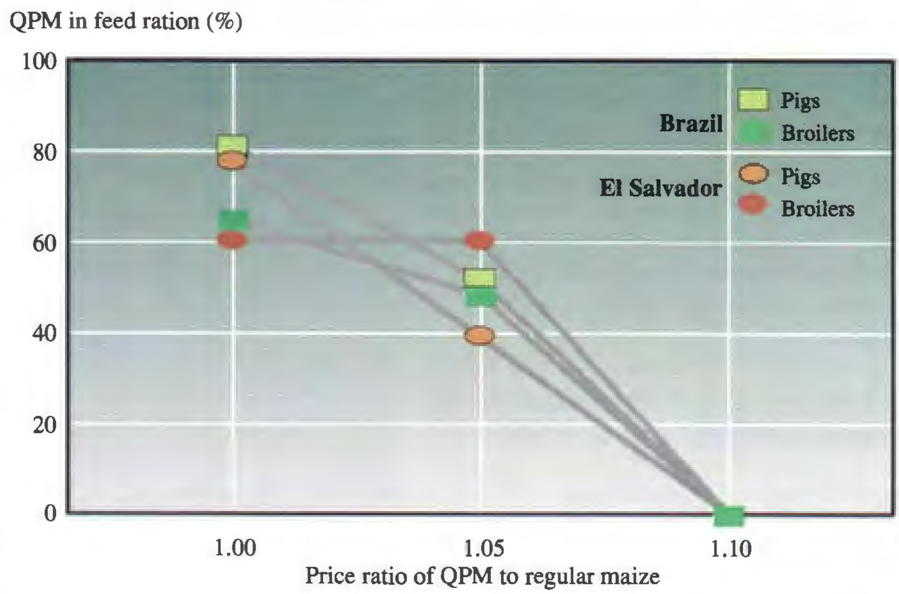


Figure 12. Content of quality protein maize in pig and chicken feed at different ratios of QPM price to regular maize price, Brazil and El Salvador.

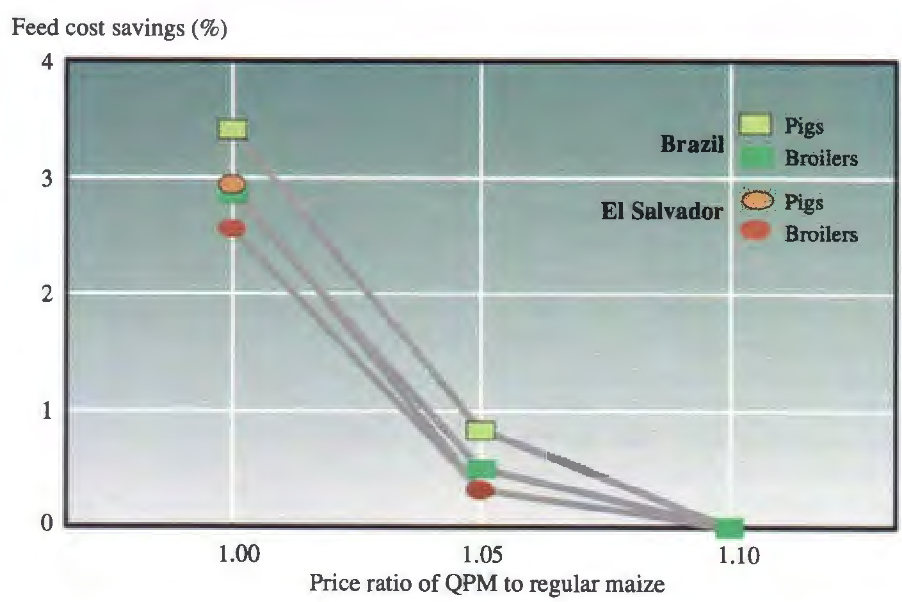


Figure 13. Cost savings from using quality protein maize in pig and chicken feed in Brazil and El Salvador, at different ratios of QPM price to regular maize price.

farmers growing maize under contract for the feed industry. The possibility that QPM could be used by the commercial feed industry is much greater in Brazil. It remains to be seen whether QPM will actually be adopted as an animal feed component in either country. However, this study indicates that some potential exists for adoption, even though farmers would most likely have to sell QPM at the same price as regular maize.

> Aside from evaluating the impacts of past research, researchers and policy makers are often concerned with determining the likelihood that future research will efficiently produce results.

Assessing Returns to Wheat Breeding Research in Nepal

Another aspect of the Economics Program's work related to impact is the study of returns to particular research investments at the national level. In 1991, we collaborated with the Nepali national program and CIMMYT's Wheat Program to assess returns to wheat breeding research in Nepal.

Two conditions influence how one measures the benefits of wheat research in Nepal. First, India's large national wheat breeding program produces improved wheat varieties that disseminate from farmer to farmer across the border to Nepal, where they grow well. However, the wheat breeding program in Nepal accelerated the diffusion of modern wheat varieties (MVs) based on germplasm from India and elsewhere. Second, although the MVs do not yield much more in farmers' fields than the varieties they have replaced, they resist disease far better and have prevented yields from declining.

When these conditions are taken into account, the internal rate of return to wheat breeding research from 1960 to 1990 is estimated to be 75% — within the range reported for other developing country breeding programs. The implications of these findings extend beyond Nepal to other small countries, which may consider supporting modest wheat breeding programs if they can benefit from germplasm developed by national programs in larger countries.

Can Wheat Work in Sudan? A Study of Comparative Advantage

In some instances, national researchers and policy makers are less concerned with evaluating the impact of agricultural research than with determining the likelihood that specific types of research can efficiently produce results. In Sudan, where the government seeks to improve self-sufficiency in wheat production, policy makers need to know whether investing in increased wheat production will actually produce the desired results or whether Sudan's resources (and those of its farmers) would be better invested in other enterprises.

In 1990, the Economics Program initiated a study of the comparative advantage of wheat production in Sudan's Gezira irrigation scheme. The study, based partly on an extensive survey of wheat producers in Gezira, examined the efficiency of producing wheat under three levels of technology compared to producing alternative crops, especially cotton. At present, it is more efficient for Sudan to produce wheat in Gezira using a full complement of improved technologies than to produce long- and medium-staple cotton. Producing wheat using the traditional practices followed by most Gezira farmers, as well as producing wheat with an intermediate improved technology, is highly inefficient compared to growing cotton.

These results imply that, to make wheat farming in Gezira efficient, Sudan must overcome some serious obstacles. Increasing farmers' yields — not just the area sown to wheat — is imperative. Furthermore, the gap between farmer's wheat yields in Gezira and potential yields needs to be closed. This may be difficult, given that it is not yet certain whether the improved wheat technologies will be so successful in parts of Gezira where water shortages are severe. The technology will therefore have to be more widely tested on Gezira's farms. Sudan will have to promote adoption of the improved wheat production practices quite vigorously, not only through extension but also through policies designed to reduce the heavy tax on agriculture and foster an efficient allocation of resources, especially agricultural inputs.

Adoption and Impact: Sharing What We Have Learned

Aside from generating information useful in specific countries or regions, the research described above has added to our understanding of how to conduct studies of research impacts at different levels and for different purposes. To consolidate part of our experience with this work, we are developing a guide to conducting adoption surveys. The guide will focus on ways of designing studies that describe patterns of adoption and also indicate whether a technology is suited to farmers' objectives and resources. Attention will be given to understanding the various institutional factors (such as extension, input supply policies, seed production systems) that may strongly condition the adoption of new technology. By sharing our experiences in this area with other researchers, we believe we can make a positive contribution to achieving our common goals.

Research Support Services

J.L. Castillo

Until fairly recently, agricultural research took place in a relatively open environment. Germplasm, new technologies, and information were rather freely exchanged within the global, public sector research community. New technologies, however, are themselves changing the nature of cooperation.

The high cost of cutting edge technologies and their apparent profitability have given impetus to concern about ownership of associated products and processes. Science is increasingly influenced by patents and other legal restrictions, a change that could have important consequences for developing countries and for CIMMYT.

The fast pace at which modern science develops technologies with potential applications in agricultural research is providing a rapidly evolving array of new options for CIMMYT and other international research centers. We are approaching this treasure trove of new tools applicable to plant breeding with care, first testing, then selecting, and, in some cases, developing those techniques best suited to our needs and those of our clients, the national agricultural re-search systems in developing countries. Here we highlight CIMMYT's application of three such techniques: genetic transformations in maize, geographic information systems, and a pedigree management system for wheat.

Using Genetic Transformations in Maize

Of the range of biotechnologies with potential applications in plant breeding, CIMMYT has initially concentrated on the use of restricted fragment length polymorphisms (RFLPs) (CIMMYT 1991) for making the crop programs' efforts more efficient. In wheat, for example, RFLPs are being applied to pinpoint the genes that control durable rust resistance in bread wheat. RFLPs are also being used to determine which genes are responsible for drought tolerance and Russian wheat aphid resistance in barley, a crop that is easier to analyze molecularly than wheat. Because the wheat and barley genomes are very similar, results obtained in barley are applicable to wheat as well.

In maize, RFLP mapping has made it possible to identify nine regions of the genome that contribute to southwestern corn borer resistance in a large segregating population derived from a cross between one resistant and one susceptible inbred line. In addition, various regions of the maize genome were found to be associated with other morphological traits measured in the same cross. Ongoing tests will determine whether the same genes for southwestern corn borer resistance are present in other segregating maize populations.

Genetic transformation — the physical insertion of alien genes into regenerated plant cells — may provide a method of introducing desirable agronomic traits into maize. Although efforts to genetically transform temperate maize are already underway in the private sector, it is unlikely that private companies will invest in similar work with the types of tropical and subtropical maize that predominate in developing countries. In an effort to satisfy the needs of its clients, CIMMYT has started preparatory work on a special project to be funded by the United Nations Development Programme (UNDP) that will develop genetic transformation protocols for enhancing insect resistance in tropical maize and facilitate the transfer of this technology to selected developing countries. The results of this research would ultimately provide farmers in developing countries with maize

J.L. Castillo

Advances in tissue culture research now allow us to obtain fertile progeny from embryogenic calli of tropical maize; these small plants later developed normal tassels and ears.

varieties that will better resist the attack of insect pests, thus reducing production losses.

The major insect pests attacking maize in the field and in storage are lepidopteran insects such as southwestern corn borer, fall armyworm, and corn earworm. Despite the economic importance of lepidopteran insects, few developing country farmers attempt to control them, either because their access to appropriate control measures is limited or because they lack confidence in their effectiveness. Farmers who do combat the pests, however, usually apply chemical pesticides that can have long-term deleterious effects on the environment. A viable alternative would be control measures that are environmentally sound and pose no danger to human health as, for example, genetically engineered tropical and subtropical maize varieties with durable insect resistance.

The project's approach to developing improved insect resistance in maize through gene transfer involves various steps. The basic objective will be to insert a gene from the soil bacterium *Bacillus thuringiensis* (B.t.) into cells of receptive maize genotypes. The B.t. gene codes for a protein that is toxic to specific lepidopteran insects, and maize plants possessing it could thus be expected to have the same poison-producing capability. Although some B.t. genes have already been identified as having high levels of toxicity to lepidopteran insects pests of temperate maize, additional tests will be necessary to determine whether any of them possess adequate toxicity to the lepidopteran insects that attack maize in the tropics.

The preparatory phase of the project aims at identifying tropical maize genotypes capable of generating complete, fertile plants from immature embryos. Testing was initiated in 1991 by the tissue culture unit of CIMMYT's Biotechnology Laboratory. The unit is presently staffed by one senior scientist and two laboratory assistants. They have progressed to the stage where a small quantity of seed produced by regenerated plants has been harvested and is waiting to be tested in the field.

The first step in testing the regenerative capacity of maize genotypes involves removing immature embryos from ears harvested 18-20 days after self-pollination and placing them in a culture medium containing a mixture of nutrients and plant hormones that promote the formation of an embryogenic callus. The resulting calli are subcultured on a medium that encourages regeneration, and the number of plantlets generated is counted. The plantlets are transferred to small pots containing specially prepared soil and grown under controlled conditions; later they are replanted in the greenhouse. If all goes well, in due time they produce seed. The seeds are planted in the field to determine whether the regenerated material is fully fertile and whether its morphological and agronomic traits have been altered. Finally, cells of genotypes that have demonstrated their embryogenic capacity both in the laboratory and in the field would receive the toxin-encoding B.t. gene. The transgenic lines thus obtained would ultimately be incorporated into CIMMYT's breeding programs and those of national programs working with tropical germplasm.

CIMMYT approaches the new tools applicable to plant breeding with care, first testing, then selecting, and sometimes developing techniques best suited to our needs and those of our clients.

CIMMYT's Geographic Information System (GIS)

Essential to our strategy for developing improved maize and wheat germplasm is the concept of mega-environments. Each mega-environment spans an area of at least one million hectares, but the territory it covers is not necessarily contiguous and may be located on more than one continent. Inclusion in a particular mega-environment is determined by the uniformity of such factors as climate, types of stress, grain preferences, and production systems; a specific genotype should thus perform similarly anywhere within it. Aided by this concept, crop programs at CIMMYT are able to focus their breeding activities on the specific germplasm needs of each mega-environment.

One versatile and promising method for fine-tuning and updating the demarcation of mega-environments is to use a Geographic Information System (GIS) such as the one that began operating at CIMMYT in 1991. A GIS facilitates the collection, storage, retrieval, transformation, and display of spatial, or geographic, information. Its database contains information that may be derived from sources as diverse as maps, aerial photography, farm-level surveys, space platforms, census results, field observations, and variety trials. As a result, a GIS can match a given location to its corresponding mega-environment, even in areas with highly variable soil, climatic, and topographic conditions, thus making valuable contributions to the delineation of maize and wheat ecologies throughout the world.

Based on quantitative data, a GIS generates more complete descriptions of environmental factors that are critically important to crop improvement research. CIMMYT's GIS can also provide a quantitative description of specific locations by drawing upon global environmental data sets, trial performance data, crop environment models, and long-term daily meteorological information. In another application, a GIS brings together results from crop models based on daily meteorological data and extrapolates them, for example, to describe potential crop production risks in remote areas.

In the short time since its inception, CIMMYT's GIS has made significant contributions to our research activities. Its two major applications have been to help determine maize mega-environments within Mexico and to provide a more accurate delineation of wheat mega-environments in Southeast Asia. In addition, the GIS's agroclimatologist is collaborating with the International Maize Testing Program to identify test sites that best represent a given set of environmental conditions and match collaborator test sites to their corresponding mega-environments. CIMMYT's Economics Program has called upon the GIS to provide support in assessing farmer adoption patterns as part of a study being conducted in the southern Veracruz, Mexico. The study's objective is to determine where and why farmers have adopted Mucuna, a nitrogen-fixing leguminous plant used to upgrade soil fertility and control erosion. A GIS's ability to pinpoint differences in soil and other conditions within small areas makes it an invaluable tool for this type of research.

The same type of support is proving extremely useful in another Economics project, this one related to maize farming systems in Kenya, in which the GIS is helping to design a maize survey that will include environment types among the parameters used in the sampling strategy. After the survey, it will assist in relating farming practices to specific environments. Based on the results of this activity, a GIS can make extrapolations that allow farming practices used for solving a problem at a specific location to be targeted to environments with similar problems anywhere in the world. Because of the enormous amounts of data involved, such extrapolations would be very difficult to do without a GIS.

Essential to implementing CIMMYT's GIS is establishing links with institutions that build spatial databases. Another challenging task will be to contribute to the integration of crop environment models with GIS databases. Finally, plans to expand GIS activities at CIMMYT and perhaps to other CGIAR centers are going forward based on the potential that the system has demonstrated during its first year in operation.

Software Development

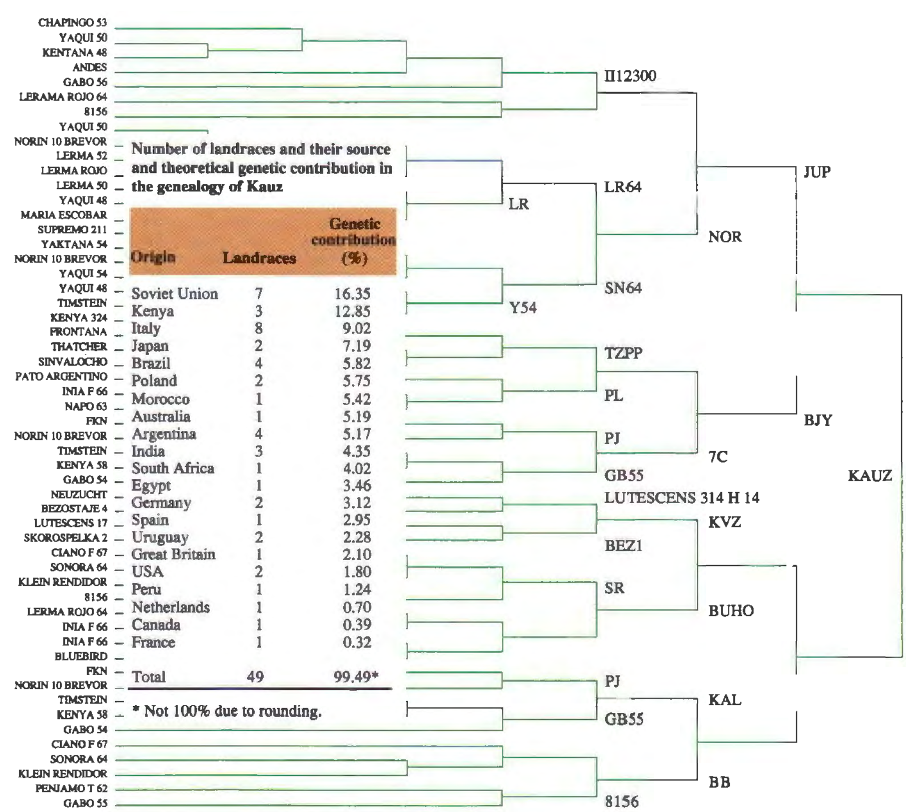
The principal functions of the software development unit are to design and develop new software systems for handling highly specialized tasks, enhance existing systems, and give corrective maintenance to operational systems of varying size and complexity. Design and development are by far the most demanding tasks, for they involve analyzing needs; designing, developing, and testing new programs; and training potential users. Most software programs developed by the unit are institution specific and require not only skilled programming, but also agricultural insight.

Both these elements came together in the wheat pedigree management system (WPMS), recently completed in close collaboration with CIMMYT's Wheat Program. The WPMS is part of the integrated wheat information system, a larger project that aims at unifying the wide range of information available on wheat germplasm (Skovmand et al. 1992). Over the years, various systems have been used to identify and describe both the original and the evolving materials with which the Wheat Program works. As the volume of materials increased, it became clear that a new system would be needed to integrate these systems, organize the vast amount of germplasm data, and to make the germplasm itself more readily accessible to breeders.

In response to this perceived need, the Wheat Program moved to create an integrated information system that would include a component for managing pedigrees (the WPMS), one for organizing germplasm descriptions and information, and one for managing data. Through this integrated system the Wheat Program hopes to bring together information from different sources, such as national and international trials, laboratories, and germplasm banks. To facilitate information exchange among crop breeding sections, the system's three components will use the same identifiers.

At the core of the integrated system is the WPMS. It is a repository of information on genealogies and selection histories that provides a uniform and user-friendly identification mechanism to store data on germplasm in terms of parental relationships in a cultivar or line's genealogy. Systems used in the past were cumbersome and made it very difficult to unequivocally identify specific germplasm and, ultimately, to share information about it. Germplasm could be identified by cultivar name, breeder name, crosses, cross number, or selection history. For example, spring wheat variety Seri 82 is also known as Veery #5, KVZ/BUHO//KAL/BB, and CM33027-F-15M-500Y-0M. The WPMS, however, will facilitate positive identification by indicating that all these descriptors refer to the same material.

Other functions of the WPMS involve generating field books for the wheat breeding sections and producing reports on such things as cross expansions, dendrograms (Figure 14), and wheat abbreviations. Yet another valuable activity of the system will be to determine the genetic contribution of any line, variety, or landrace to a particular pedigree. By comparing sets of landraces in family trees of modern varieties, breeders will be able to trace useful traits to specific landraces and identify the ones that have not as yet been used in improvement programs.



Number of landraces and their source and theoretical genetic contribution in the genealogy of Kauz

Origin	Landraces	Genetic contribution (%)
Soviet Union	7	16.35
Kenya	3	12.85
Italy	8	9.02
Japan	2	7.19
Brazil	4	5.82
Poland	2	5.75
Morocco	1	5.42
Australia	1	5.19
Argentina	4	5.17
India	3	4.35
South Africa	1	4.02
Egypt	1	3.46
Germany	2	3.12
Spain	1	2.95
Uruguay	2	2.28
Great Britain	1	2.10
USA	2	1.80
Peru	1	1.24
Netherlands	1	0.70
Canada	1	0.39
France	1	0.32
Total	49	99.49*

* Not 100% due to rounding.

Figure 14. One product of CIMMYT's new Wheat Pedigree Management System is the sort of dendrogram shown here (for the bread wheat variety Kauz), which enables wheat researchers to trace the genealogy of individual cultivars and determine the theoretical genetic contributions of parental landraces.

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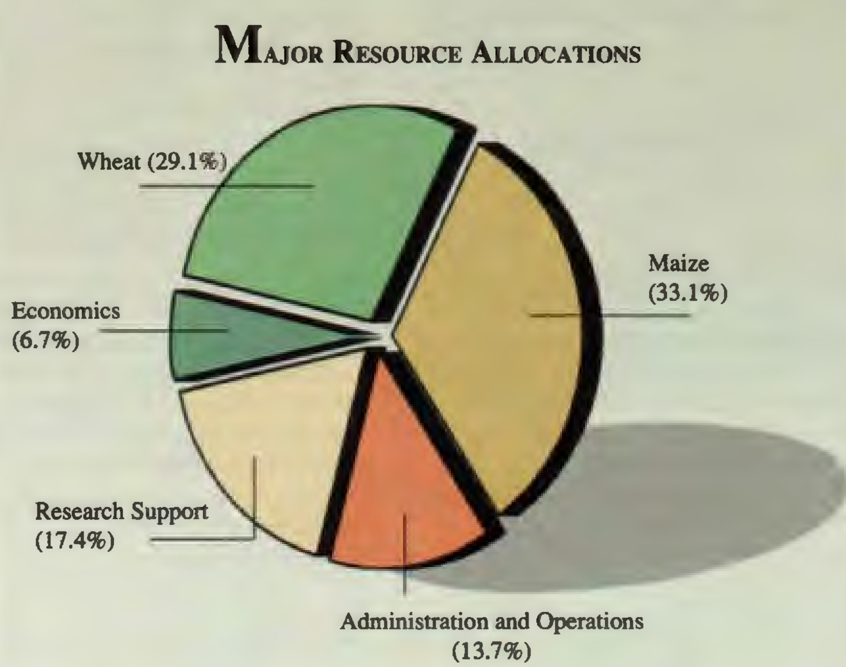
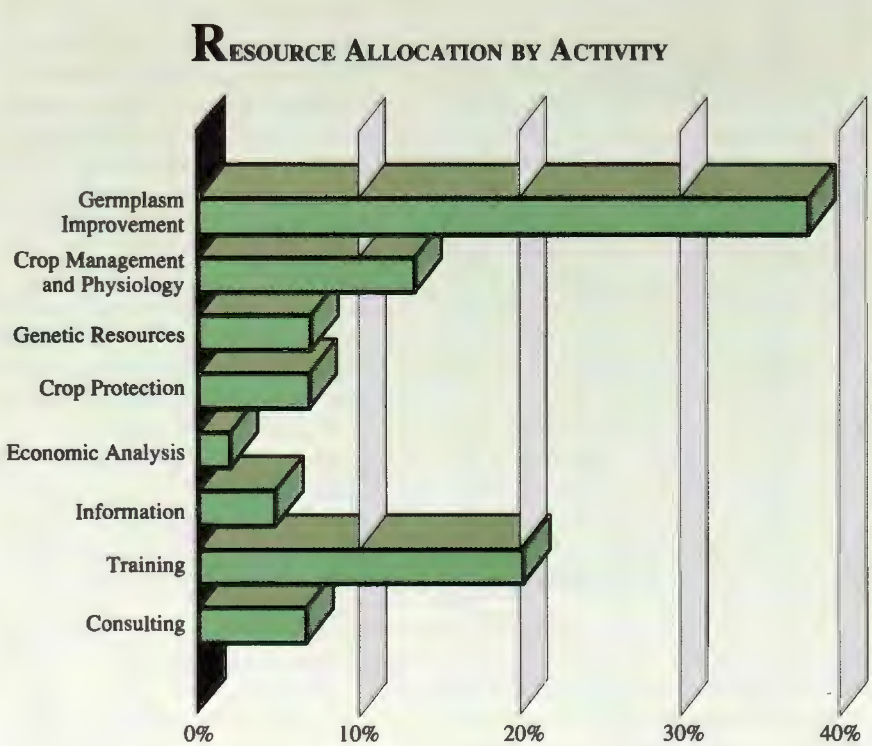
Financial Highlights





CIMMYT's strategic plan calls for increased allocations to germplasm improvement, strategic crop management research (including work on natural resources), and information work relative to other activities. These trends are generally reflected in our 1991 allocations.

These financial highlights summarize how funds were distributed by the Center in our continuing effort to effectively fulfill our mission. During 1991, germplasm improvement utilized 38.9% of the Center's resources allocated to research (see diagrams at left). Crop management, crop protection, and genetic resources activities together accounted for 27.4% of these resources. Training occupied 20.2% of the budget. Information, consulting, and economic analysis made up the rest of the allocations at a combined 13.5%.

CIMMYT's ability to fulfill its international research and training obligations obviously depends on funding. In 1991, we received funds for essential and complementary work from more than 34 donors around the world.

During the year, the Center's total assets decreased. Cash and short-term investments were down substantially, with corresponding increases in accounts receivable and decreases in payments received in advance from donors. Accounts receivable from donors continue to be higher than historical levels because of several large core donations outstanding at year end.

As a result of a change in CGIAR policy in 1991, we began to recognize depreciation on fixed assets in full compliance with accounting principles accepted in the USA for nonprofit organizations. Accordingly, the value of property, plant, and equipment has been adjusted by the new Accumulated Depreciation account in 1990 and 1991 and is reflected in the balance sheet below. A new Capital Fund account was created in 1991 as a reserve for the future replacement of physical facilities and equipment.

Donor pledges in currencies other than US dollars are recorded at their dollar equivalent on the date of deposit. In 1991, the renewed strength of the dollar against other major currencies resulted in lower than expected dollar revenues from donations denominated in other currencies. In Mexico, the combined effect of exchange rates and inflation continued to erode the purchasing power of dollar revenues received by the Center.

CIMMYT's complete audited financial statements are published as a separate document and sent to all donors. Additional copies of that document are available from the Center upon request.

Donor contributions (includes special projects)	**US$ (000s)**
Australia	674
Austria	220
Belgium	209
Brazil	30
Canadian International Development Agency	5,096
Danish International Development Agency	728
European Economic Community	2,126
Finland	904
France	493
Germany (BMZ)	505
India	52
Inter-American Development Bank	2,805
International Crops Research Institute for the Semi-Arid Tropics	298
Islamic Republic of Iran	95
International Board for Plant Genetic Resources	122
International Development Research Centre	5
Italy	230
Japan	2,428
Mexico	30
Norwegian Agency for International Development	318
OPEC Fund for International Development	12
People's Republic of China	50
Republic of Korea	60
Sasakawa Africa Association	33
Spain	100
Switzerland	914
The Ford Foundation	100
The Netherlands	717
The Philippines	50
The Rockefeller Foundation	232
The United Kingdom	1,297
The World Bank	4,430
United Nations Development Programme	1,964
United States Agency for International Development	6,642
Miscellaneous Training and Research Grants	111
Total Income from Grants	**34,080**

Balance sheet (US $ 000s)	**Year ended 31 December 1991**	**1990**
Assets		
Cash and short-term deposits	1,321	4,306
Accounts receivable		
Donors	7,122	6,569
Other	1,247	1,026
Inventories	152	145
Prepaid fixed assets,	430	..
Property, plant, and equipment	25,022	24,547
Accummulated depreciation	(12,834)	(11,954)
Total Assets	**22,460**	**24,639**
Liabilities and Fund Balances		
Liabilities		
Accounts payable and other liabilities	1,875	1,736
Accrued staff obligations	818	882
Payments in advance from donors	2,859	5,338
Total liabilities	5,552	7,956
Fund Balances		
Property, plant, and equipment	12,188	12,593
Capital Fund	264	
Subtotal	12,452	12,593
Other Funds	3,965	3,645
Operating	2,765	2,765
Auxiliary services	234	192
Cumulative translation effect	(2,508)	(2,512)
Subtotal	4,456	4,090
Total Fund Balances	16,908	16,683
Total Liabilities and Fund Balances	**22,460**	**24,639**

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[1] Ex officio position

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Cooperative Program with IITA in West Africa
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CIMMYT AND THE CGIAR

CIMMYT is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center is engaged in a worldwide research program for maize, wheat, and triticale. We emphasize improving the productivity of agricultural resources in developing countries while protecting the environment. The Center is one of 16 nonprofit international agricultural research and training organizations supported by the Consultative Group for International Agricultural Research (CGIAR).

The CGIAR was established in 1971 as an informal association of public- and private-sector donors interested in supporting international agricultural research. The group is sponsored by the Food and Agricultural Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). CGIAR membership now includes some 40 donor countries, international and regional organizations, and private foundations.

The CGIAR seeks to ensure that the best international agricultural research expertise is brought to bear on the problems of the world's disadvantaged peoples. In addition to research, CGIAR centers also provide training for agricultural scientists from around the world, with an emphasis on improving the capacity of developing country researchers. During the past 20 years, over 45,000 scientists have participated in CGIAR-sponsored training. Many scientists from developing countries who were trained at CGIAR centers now form the nucleus of and provide leadership to national agricultural research systems in their own countries.

Programs carried out by CGIAR-supported centers fall into six broad categories:

Productivity Research
Creating or adapting new technologies to increase productivity on farmers' fields (such as the semidwarf varieties of wheat and rice that brought about the Green Revolution in Asia).

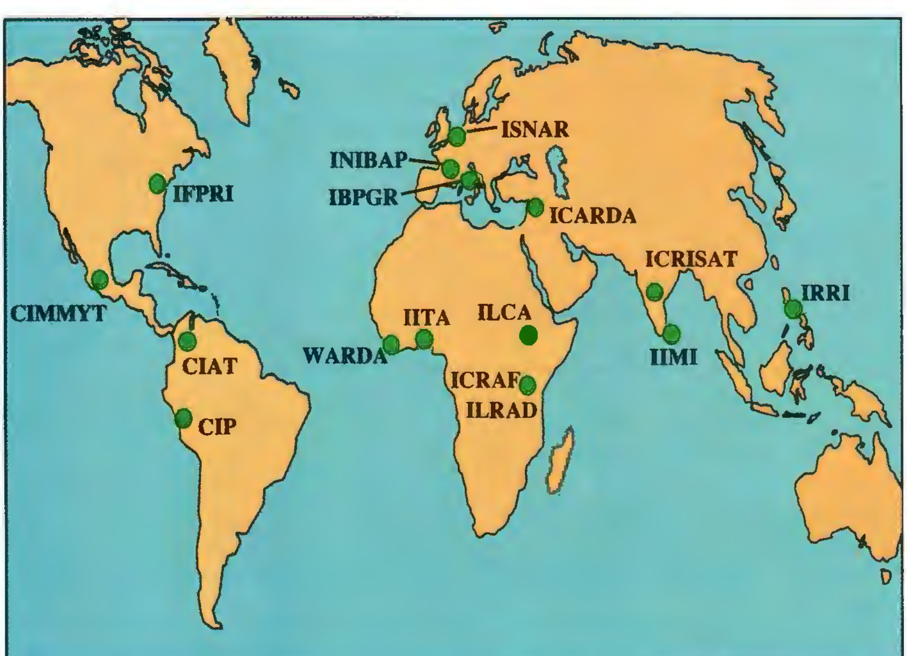
Management of Natural Resources
Protecting and preserving the productivity of natural resources on which agriculture depends.

Improving the Policy Environment
Assisting developing countries to formulate and carry out effective food, agriculture, and research policies.

Institution Building
Strengthening national agricultural research systems in developing countries.

Germplasm Conservation
Conserving germplasm and making it available to all regions and countries.

Building Linkages
Helping to create or strengthen linkages between developing country institutions and other components of the global agricultural system.



Location of CGIAR centers.

Correct Citation: CIMMYT. 1992. *CIMMYT 1991 Annual Report (International Maize and Wheat Improvement Center). Improving the Productivity of Maize and Wheat in Developing Countries: An Assessment of Impact.* Mexico, D.F.: CIMMYT.
ISSN 0257-8735

AGROVOC descriptors: Zea mays; wheats; plant breeding; developing countries; research institutions.
AGRIS category codes: A50; A01. *Dewey decimal classification:* 630.

Writing/Editing: Tiffin D. Harris, Kelly Cassaday, Gene Hettel, Michael Listman, and Alma McNab.
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Design Assistance: Ma. Concepción Castro A., José Manuel Fouilloux B., Eliot Sánchez P., and J. Luis Delgado M.
Bibliographic Compilation: Edith Hesse de Polanco, Lourdes Romero, and Miguel Angel López.

Printed in Mexico.

ISSN 0257-8735

CIMMYT 25
1966·1991

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