

CROP VARIETY IMPROVEMENT AND ITS EFFECT ON PRODUCTIVITY

The Impact of International Agricultural Research

Crop Variety Improvement and its Effect on Productivity

The Impact of International Agricultural Research

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CABI Publishing is a division of CAB International

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Oxon OX10 8DE
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44 Brattle Street
4th Floor
Cambridge, MA 02138
USA

Tel: +44 (0)1491 832111
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E-mail: cabi@cabi.org
Web site: www.cabi-publishing.org

Tel: +1 617 395 4056
Fax: +1 617 354 6875
E-mail: cabi-nao@cabi.org

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A catalogue record for this book is available from the British Library, London, UK.

Library of Congress Cataloging-in-Publication Data

Crop variety improvement and its effect on productivity : the impact of international agricultural research / edited by R.E. Evenson and D. Gollin.
p. cm.

Includes bibliographical references (p.).

ISBN 0-85199-549-7 (alk. paper)

1. Field crops--Breeding. 2. Field crops--Genetics. 3. Crop improvement. 4. Agriculture--Research--International cooperation. 5. Agricultural productivity.
I. Evenson, Robert E. (Robert Eugene), 1934-

II. Gollin, Douglas

SB185.7 .C76 2002

631.5'2--dc21

2002011122

ISBN 0 85199 549 7

Typeset in Melior by Columns Design Ltd, Reading
Printed and bound in the UK by Biddles Ltd, Guildford and King's Lynn

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Foreword

H. GREGERSEN

(Chair, CGIAR Standing Panel on Impact Assessment)

The development of improved, fertilizer-responsive high-yielding varieties of wheat and rice during the early 1960s and their widespread adoption by farmers, first in Asia and then in Latin America, marked the beginning of what is known as the 'Green Revolution'. Much has been written about this technological breakthrough and its impacts – both positive and negative – in the years since its effects were first felt in farmers' fields across Mexico, India, the Philippines and beyond. Since then, improving crop germplasm and the development of new varieties through well focused crop breeding programmes have been extended to many other food and feed crops in developing countries. Today, there are few crops of major economic importance that have not benefited from the application of scientific crop breeding. Each crop has its own story to tell, as evident in this book.

There are many critics of the Green Revolution – those who insist that the impacts have not been that large or that, on balance, the impacts have not been positive (due to adverse environmental effects). Anecdotal evidence and specific case study examples are often cited in support of large positive effects as well as negative ones. The core of the debate centres on the nature and size of the impacts from improvements in the crop germplasm. The total gains achieved have relied on the joint efforts of the national agricultural research systems (NARS) and the international agricultural research centres (IARCs) of the Consultative Group for International Agricultural Research (CGIAR). Commercial crops also have relied heavily on active private sector breeding programmes.

While individual CGIAR centres in the past have undertaken isolated case studies of these impacts, there has, to-date, been no comprehensive crop-wise regional analysis of the aggregate impacts of the IARC and NARS germplasm improvement efforts over the years back to the early days of the Green Revolution.

In 1998, the CGIAR's independent Standing Panel on Impact Assessment (SPIA), which was then called the Impact Assessment and Evaluation Group (IAEG), initiated a major study of the impact of CGIAR's germplasm improvement activities since the beginning of the Green Revolution. SPIA was fortunate to get Professor Robert Evenson of Yale University to coordinate the study in collaboration with the eight crop-based IARCs of the CGIAR, namely CIAT, CIMMYT, CIP, ICARDA, ICRISTAT, IITA, IRRI and WARDA.¹ Professor Evenson was joined by Professor Douglas Gollin of Williams College in producing the overall study and the synthesis of the individual crop assessments. The study remains a collaborative effort of the CGIAR centres and Professors Evenson and Gollin. It builds on the impact assessment work undertaken by the CGIAR centres and their NARS partners to monitor and document the released varieties and the corresponding adoption rates and production gains for individual crop commodities. In addition, country case studies were undertaken for China, India and Brazil that provide further insights into the impacts of the CGIAR and NARS crop germplasm improvement (CGI) activities in some of the major countries where Green Revolution technologies have been applied. The overall study took more than 5 years to complete. Progress reports were presented at almost every CGIAR Annual and Mid Term meeting since 1999.

SPIA and the CGIAR owe a tremendous vote of thanks and gratitude to Professors Evenson and Gollin and to the individual authors from the CGIAR centres and the NARS for their hard and time-consuming work in completing this study.

Quite aside from the authors, many people and organizations gave of their time and resources to make the study possible. SPIA would in particular like to thank Alexander von der Osten and Ravi Tadvalkar and the CGIAR Secretariat for their significant support of the study from its inception. Major credit goes to FAO, the World Bank and UNDP, the Co-sponsors of the CGIAR, who so generously supported the study over its lifetime.

SPIA also thanks Dr Tina David, who served as SPIA focal point for the IARCs and study coordinators on behalf of SPIA; and it wishes to give special recognition to Dr W. James Peacock, the chair of the IAEG when the study was initiated and to Dr Tim Healy, who acted as manager of the project in its early stages. SPIA also gives a strong vote of

¹ See list of acronyms on p. xxiii for the full names of these centres.

thanks to Dr Peter Matlon, then of the UNDP and now with the Rockefeller Foundation, who gave support, guidance and outstanding advice that helped to shape the study and move it along to completion. For several years, Dr Guido Gryseels, formerly of the CGIAR/TAC Secretariat and Executive Secretary to SPIA, managed the details of the program; and SPIA gives special thanks to him. The design proposal was prepared by Professor Greg Traxler of Auburn University in 1997. SPIA gives thanks to him for preparing a proposal that stressed common methodology and rigorous analysis. In fact, throughout the 5 years in which the study was active, SPIA and the study directors have insisted on maintaining the standards called for in the initial proposal and agreement. Annual meetings were held with the teams to monitor progress, and to exchange views, information and insights developed along the way to study completion.

Finally, SPIA also wishes to express its appreciation to the three anonymous external referees who provided significant and helpful suggestions on earlier drafts, particularly with respect to the testing of different specifications of the models for the country studies and synthesis chapters, the inclusion/exclusion of specific exogenous variables in a number of equations, the use of appropriate statistical tests where relevant and, finally, in highlighting a number of analytical difficulties, limitations and qualifications of the study. While the authors could not respond directly to all the concerns raised by the reviewers, SPIA is confident that the authors have responded to the key issues in a positive and satisfactory manner and have in the study acknowledged others that could not be dealt with adequately, given the limitations in data, time and resources.

While certainly not exhaustive, this work provides the most comprehensive documentation of crop genetic improvement impacts to date. The study covers both the production and diffusion of improved crop varieties for 11 important CGIAR mandate food and feed crops in developing countries over the period from 1960 through to the 1990s.

Through this study, Professors Evenson and Gollin and the team of centre and NARS colleagues have been able to bring together a wealth of data and information to address some long-standing questions regarding the impacts of the CGIAR System and its partner researchers around the globe. Taken as a whole the chapters provide a major milestone in the analysis and documentation of the impacts of crop genetic improvement work over the last 40 years.

To meet the study's major objectives, Evenson and his colleagues had to trace through five interlinked steps:

- First, they needed to establish the nature and magnitude of outputs of the various CGI programmes, including those of the NARS and private sector, and the associated costs of those investments.

- Second, they needed to estimate the varietal make-up of the released varieties in order to establish the direct and indirect CGIAR content thereof, providing an estimate of the CGIAR contribution to all released varieties.
- Third, they needed to estimate adoption rates and production gains between the new varieties and those replaced. This gave them a measure of the production gains related to the CGIAR contribution.
- Fourth, by introducing these production gains into various economic market models, they were able to estimate the economic gains (impacts) on consumers and producers through changes in prices, production, trade, consumption and nutrition.
- Fifth, they needed to assess IARC effects on NARS and private sector investments in CGI programmes in order to establish the appropriate counterfactual situation, i.e. what would have happened without any CGIAR input.

While the results and conclusions of the study are detailed in the chapters that follow, it is worthwhile to summarize the important ones here. Keeping in mind that there are marked differences in results between crops and between regions, the basic conclusions of the overall study can be summarized as follows:

- NARS and the IARCs continue to produce high levels of modern varieties (MVs) of crops. The data do not support the view that diminishing returns to varietal production have set in. Indeed, the rate of MV production as measured by releases has been steadily increasing for all crops in all regions, except for wheat and rice in Asia and Latin America where it has been roughly constant since 1985. In the 1990s MV production for all crops was more than double the rate in the 1970s, and four times the rate in the 1960s. For example, average annual wheat varieties released by national programmes rose from just over 40 between 1965 and 1970 to more than 80 between 1986 and 1990.
- IARCs and NARS have been the main producers of MVs in developing countries. Private firms produced some MVs, mainly as hybrids for maize, sorghum, millet and, more recently, rice. Moreover, private firm MV production has relied heavily on open pollinated ‘platform’ MVs generated by the IARCs and NARS programmes. Developed country organizations produced very few MVs for developing countries. NGOs generally did not produce MVs.
- IARC germplasm services provide a very important input to NARS crop germplasm improvement programmes. IARC content in released MVs was high for most crops. More than one-third of the approximately 8000 released crop varieties were crossed in an IARC programme. (For the Middle East and North Africa and for sub-

Saharan Africa, they accounted for more than half of all modern varieties released.) In addition, 17% of all NARS varieties relied on at least one IARC-crossed parent and another 23% relied on IARC ancestors.

- IARC programmes are both complementary to and competitive with NARS programmes. In examining the effect of IARC CGI programmes on NARS investments, Evenson found that for countries with small acreage planted to the crop or with low population densities, the competition effect was dominant, while for the largest countries and those where rural population densities are higher, the complementary effects dominated. When weighted by population, the complementary, i.e. enhancement, effects dominate. For all countries weighted by hectares planted, the net complementary effect of the IARCs produced roughly 15% more NARS CGI investment.
- The direct contribution of IARC programmes relative to the investment of resources is substantial. The proportion of total varieties produced by IARCs was well above their proportion of total resources invested in such production.
- With respect to adoption, the percentage of area planted to improved varieties was low for most crops (wheat in Asia is the exception) but has steadily grown such that presently improved varieties are dominant for most crops in most regions. IARC crosses are planted on roughly 36% of the area planted to MVs.
- With respect to production impacts, the conclusions from both the individual IARC case studies and from the three country studies show that without the IARCs the number of released varieties would have been 45–60% less (depending on assumptions).
- CGI contributions to annual productivity growth have been estimated by Evenson for all crops, by region and by decade. Growth from varietal improvement has been realized in all crops, but at very different rates by region. By the 1990s, all crops except beans were realizing high growth rates in productivity through varietal improvement. The average annual growth in productivity from CGI across all crops and regions between 1960 and 1998 was 0.718%, with the highest rates in Asia and the lowest in sub-Saharan Africa. Interestingly, crop productivity growth through breeding was higher in the 1980s and 1990s (averaging 0.830% per annum) than in the previous two decades (averaging 0.321% for the 1960s and 0.676% in the 1970s).
- The IARC contribution to the CGI gains has also been estimated via the counterfactual estimation. Depending on the assumptions used about substitution effects, and depending on the crop and the region, IARC's contribution as a share of total CGI annual growth varied between 40 and 45%.

- With respect to the economic and social consequences of CGI gains from IARC investments, Evenson and Rosegrant, using the IFPRI-based model, -IMPACT-, derive the following estimates based on their best estimates of what would have happened without the CGIAR input:
 - (i) world food and feed grain prices (weighted by production) would have been 18–21% higher than they actually were, (and 35–66% higher in the absence of any CGI activity);²
 - (ii) world food production would have been 4–5% lower – and not lower than that because of 1–2% higher production in the developed countries in response to higher prices, while developing countries would have produced 7–8% less;
 - (iii) area planted to cropland would have been significantly higher, particularly for crops like rice. For all food crops, total acreage would have expanded by 1.5–2.7% (5–6 million ha in developed countries and 11–13 million ha in developing countries).
 - (iv) food consumption per capita would have declined significantly for many groups. For all developing countries, the average reduction in caloric availability per capita would have been 4.5–5%, and up to 7% in the poorest regions. Furthermore, approximately 2–2.3% more children (13–15 million) – predominantly located in South Asia – would have been malnourished than otherwise, and infant mortality would have been higher;
 - (v) imports of food in developing countries would have been about 5% higher.

Taken together, these are indeed important achievements from sustained investments in CGI research over a period of four decades. This first-of-its-kind comprehensive assessment of CGI programme impacts provides evidence of large scale success at the global level and in virtually every region and goes a long way towards dispelling the myth that the Green Revolution is over. The impact of reduced prices in terms of food security has been significant.

The findings of this study support the proposition that IARC investments have had positive impacts for all the study crops. These impacts have been large, partly because of higher leverage through IARC-NARS joint production. The placing of crop germplasm improvement at the core of IARC programmes appears to have been well justified.

² With respect to impacts on poverty alleviation, Evenson and Gollin conclude that the poor would have been hurt more by the higher prices in the absence of the CGIAR because they spend a higher share of their income on food.

At the same time, given the impression in some quarters that there have been significant environmental and other negative impacts from application of the Green Revolution technologies, SPIA commissioned other studies to look at such impacts. One of the outputs from this work has recently been published (Maredia and Pingali, 2002), while another is in the final editing stages (Nelson and Maredia, 2003). The conclusions of these authors is that yes, there have been some negative environmental impacts, but there also have been counterbalancing positive environmental impacts, particularly related to land savings. (More intensive production and greater output per hectare mean that less land would be required to produce a given output of food crops.)

SPIA wishes to congratulate Professors Evenson and Gollin and their colleagues in the IARCs for the important results and insights of this study on the impacts of CGI work in the CGIAR.

This has been a courageous and ambitious undertaking, fraught with many data constraints and methodological challenges. The study is based on an impressive amount of data and results, as shown in the accompanying tables and appendices. In fact the voluminous data accumulated for the study are far more than reasonably could be interpreted or commented on in any one book. While the authors have sought to highlight the key results and their interpretation in the brief narrative of each chapter, much more could still be said, debated and speculated upon. The reader is encouraged to consider the results of this study as a first approximation, an initial attempt in quantifying the benefits from CGI over the past four decades. We hope this will provide the impetus for a second generation of studies to confirm, to further explore, and to question some of the conclusions reached here, using new data, different methods and statistical tests, and different scales.

In the meantime, we believe that these findings represent a milestone in the assessment of the impacts of crop genetic improvement research and development, and that they will be of interest and use to many for a long time to come, but particularly to the NARS, the CGIAR members, centres, and Science Council, and to the broader community interested in the value and impacts of agricultural research.

As the authors conclude in the final chapter of the study, 'Consumers benefit most and poor consumers benefit most of all from agricultural research. Farmers are consumers too and for the world's smallest farm producer the total consumer gains are large.' From the producers' side, benefits also accrued. By adopting improved varieties, many farmers lowered costs of production and generated higher rates of return from their land, labour and capital. This, in turn, had positive impacts on income and helped reduce poverty in both land owning and labour producing households in some agricultural regions, but by no means all. An indirect spillover effect from modern variety adoption in

other areas was declining crop prices. In the areas not touched by the Green Revolution, costs of production did not fall, and this, in turn, had an adverse effect on farmers' incomes in these regions. Crop germplasm improvement programmes have not yet delivered suitable crop varieties to them. Yet, for many this still represents the most promising way out of poverty. Thus, a key challenge now for the CGIAR and its NARS partners is to target CGI research investments to farmers who have thus far been bypassed by the Green Revolution, primarily in those resource-poor, marginal environments where modern varieties have not been adopted.

Acknowledgements

This book was inevitably the product of many individuals. Our main burden of obligation is clearly to all the authors who participated in the research reported here. We have appreciated the generosity of their contributions and their willingness to respond, often at short notice, to requests for information. We asked them to deliver the impossible – and we responded by editing and condensing their contributions, often drastically. For their forbearance and energy, we thank them.

In addition to the authors whose names are included on the individual chapter headings we acknowledge the many unnamed research assistants, enumerators, support staff, and clerical staff who have helped to collect and interpret the data, often under difficult circumstances. Most of these individuals carried out their efforts under the auspices of the international agricultural research centres of the Consultative Group on International Agricultural Research and their numerous national partners. These institutions deserve further credit for devoting time and resources to answering questions about impact.

We also thank, without naming, the numerous agricultural scientists who took time to answer their colleagues' impertinent questions about the impact of varietal improvement. We would like to believe that in many institutions, impact assessment work has opened up channels of communications between natural scientists and social scientists.

At a more specific level, this study owes a great deal to the members of the Standing Panel on Impact Assessment (SPIA) of the CGIAR's interim Science Council. In particular, we thank Hans Gregersen, Guido Gryseels and Tim Kelley for their contributions to the conceptualization

and execution of the study, as well as Christina David, the focal point within SPIA and Peter Matlon, the focal point within the UNDP. The authors also wish to express their appreciation to the Cosponsors of the CGIAR (FAO, WB, UNDP) for generously supporting, through SPIA, this initiative.

We received valuable comments on this research from Dana Dalrymple, Don Duvick and Guy Manners. Cheryl Doss read and commented on several portions of the manuscript. Michael Morris provided helpful comments on several chapters. Three anonymous referees made detailed and important suggestions that greatly strengthened the manuscript. We also benefited from the comments of students at Williams College and Yale University.

Bob Evenson received outstanding research assistance from Iñez Tristao and Fabiana Tito.

At CABI *Publishing*, Tim Hardwick, Claire Gwilt and Rachel Robinson shepherded this volume along, addressing the inevitable delays and corrections with apparent patience and good nature.

We gratefully acknowledge institutional support from the Economic Growth Center at Yale University and from the Gaylord Donnelley Fellowship, given by the Yale Institute for Biospheric Studies, which supported Gollin during part of the preparation of the manuscript.

Finally, we would like to acknowledge the heroic efforts of Kathy Toensmeier in assembling the manuscript. This involved handling text and figures in at least a dozen different software formats, dealing with two editors (occasionally working at cross purposes) and more than a dozen sets of contributors. Without Kathy's determination, this book would never have found its way into print.

Acronyms and Abbreviations

ACA	alternative coconut ash
AICMIP	All India Coordinated Millet Improvement Project
AICSIP	All India Coordinated Sorghum Improvement Project
BGMV	bean golden mosaic virus
BRRI	Bangladesh Rice Research Institute
c.i.f.	cost, insurance, freight (included in price)
CGI	crop genetic improvement
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Centre for Tropical Agriculture (Colombia)
CIMMYT	International Maize and Wheat Improvement Centre (Mexico)
CIP	International Potato Centre (Peru)
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
CLAYUCA	Consortio Latinoamericano de la Yuca
CMS	cytoplasmic male sterility
COD	coefficient of diversity
COSCA	Collaborative Study for Cassava in Africa
CPRI	Central Potato Research Institute (India)
CRRRI	Central Rice Research Institute (India)
DM	downy mildew
DRR	Directorate of Rice Research (India)
ECA	Economic Commission for Africa
ECABREN	Eastern and Central Africa Bean Research Network
EMBRAPA	Brazilian Agricultural Research Corporation

ES	economic surplus
FAO	Food and Agriculture Organization of the United Nations
FLAR	Latin American Fund for Irrigated Rice
GARB	gross annual research benefit
GEB	gross economic benefit
GRU	genetic resource unit
GTZ	German Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit)
HYV	high-yielding variety
IAEG	Impact Assessment and Evaluation Group
IARC	international agricultural research centre
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas (Syria)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (India)
IDRC	International Development Research Council
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IICA	Inter-American Institute for Agricultural Cooperation
IITA	International Institute of Tropical Agriculture (Nigeria)
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INGER	International Network for Germplasm Evaluation and Research
INGER-Africa	International Network for Genetic Evaluation of Rice for Africa
IRAT	Institut de Recherches Agronomiques Tropicales
IRIS	International Rice Information System
IRR	internal rate of return
IRRI	International Rice Research Institute (Philippines)
IRTP	International Rice Testing Programme
ISVHAT	International Sorghum Varieties and Hybrid Adaptation Trials
LAC	Latin America and the Caribbean
LLS	late leaf spot
MENA	Middle East and North Africa
MSV	maize streak virus
MV	modern variety
NARS	national agricultural research system(s)
NCRI	National Cereals Research Institute (Nigeria)
NIC	newly industrialized country
NPV	net present value
OAU	Organization of African Unity

OPV	open-pollinated variety
PABRA	Pan African Bean Research Alliance
PBND	peanut bud necrosis disease
PCCMF	Central American Cooperative Network for Bean Improvement
PhilRice	The Philippines Rice Research Institute
PMV	peanut mottle virus
PPP	purchasing power parity
PROFRIJOL	El Programa Coperativo Regional de Frijol para Centro América, México y El Caribe
PROFRIZA	Proyecto Regional de Frijol para la Zona Andina
RCR	real cost reduction
SABRN	Southern Africa Bean Research Network
SADC	Southern Africa Development Community
SAFGRAD	Semi-Arid Food Grain Research and Development
SMIP	Sorghum and Millet Improvement Programme
SMY	scientist man-year
SPIA-TAC	Standing Panel on Impact Assessment of the Technical Advisory Committee
SSA	sub-Saharan Africa
SSD	single seed descent
SYE	staff-year equivalent
TFP	total factor productivity
TPS	true potato seed
TV	traditional variety
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
VT	varietal turnover
WANA	West Asia and North Africa
WARDA	West Africa Rice Development Association (Côte d'Ivoire)
WCA	West and Central Africa
WECAMAN	West and Central African Maize Network

Study Design and Scope

1

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Prior to the 20th century, most crop genetic improvement was achieved by farmers through selection of seeds from superior plants. As human populations expanded into new regions, farmer selection produced increased genetic diversity in the form of distinct ‘landraces’, or traditional varieties, with different genetic characteristics within the cultivated crop species. In the first half of the 20th century, specialized crop breeding programmes were developed to exploit this farmer-created diversity to produce ‘modern’ crop varieties through systematic crossing and selection. These crop breeding programmes had by mid-century produced several generations of modern crop varieties in most cultivated species, suitable primarily for richer and more developed – and incidentally or not, temperate zone – countries.

Crop breeding programmes were much less developed in poor and tropical countries. The high degree of sensitivity of many crops to soil and climate characteristics meant that varieties suited to developed countries were seldom suited to poorer countries with different growing environments. Crop breeding programmes were thus required in many locations to produce varieties suitable for those locations. By the 1950s, few countries in the developing world possessed the research infrastructure required for effective plant variety breeding. As a result, most of the developing world lacked access to modern crop varietal technology. What was clearly needed was a model for multi-location crop breeding programmes that would utilize common breeding methods and strategies – as well as some common ‘germplasm’ in the form of parental breeding materials.

At the start of the 1960s, it was clear that private-sector firms were unlikely to make significant investments in crop improvement research targeted at the major crops grown in poor countries. Since there was no effective intellectual property protection of crop varieties at the time, few incentives existed for private company breeding programmes, except for 'hybrid' crops (i.e. varieties crossed from inbred parent lines to take advantage of heterosis effects). For hybrids, heterosis effects made first-generation seed attractive to farmers, who were willing to pay for the advantages offered by good seeds. In the 1960s, Plant Breeders' Rights were developed in order to provide incentives for private breeding programmes, and in the 1990s, conventional patent rights have been extended to crop varieties and biotechnology products. In 1960, however, most crop breeding programmes were in the public sector and were carried out at government agricultural experimental stations.

Thus, the international agencies concerned with promoting economic development after World War II were confronted with two realities. The first was that population growth was occurring at a rate that was historically unprecedented. Improvements in public and private health measures had brought about reductions in death rates in almost all developing countries. Even though birth rate declines followed death rate declines in most countries, the resultant demographic transition produced a population 'boom' in all developing countries. For some poor countries, this meant a tripling or more of population and of food demand over the second half of the 20th century.

The second reality was that most developed countries were already utilizing most of their land and water resources suited to crop production. Traditional crop improvement methods could not cope with the population-driven increases in demand.

The institutional response to these realities was to develop a system of international agricultural research centres (IARCs) funded through an international consortium of donors. This system eventually took on a formal structure as the Consultative Group for International Agricultural Research (CGIAR). Sixteen centres now form the CGIAR. Eight of these have mandates to develop technology for the major food crops in developing countries. Although some centres have a regional focus, and some are orientated towards the problems of specific regions or ecosystems, a number of institutions are directly mandated with crop-orientated research. In particular, they work with national agricultural research systems (NARS) to undertake and support crop breeding and genetic improvement.

The IARC strategy for crop genetic improvement encompasses the following:

- Developing, maintaining and evaluating basic crop germplasm collections (gene banks)

- Facilitating the exchange and use of germplasm collection materials with NARS programmes and with private seed firms
- Developing crossing and selection programmes to produce releasable varieties and/or advanced breeding lines for NARS breeding programmes (and private seed firms)
- Providing evaluations and information exchange to support the sharing and use of advanced breeding lines by NARS breeders (and private seed firms).

By the late 1960s, two IARC programmes – the International Rice Research Institute (IRRI), located in the Philippines, and the International Maize and Wheat Improvement Centre (CIMMYT), located in Mexico – were credited by the popular press with achieving a ‘Green Revolution’ in rice and wheat production. This Green Revolution was identified with the development of improved ‘high-yielding’ varieties of both rice and wheat and with the rapid adoption of these varieties by farmers in Asia and Latin America.

Today agricultural research takes place in a context profoundly different from the one that pertained 40 years ago. Astonishing new technologies have emerged, and scientific knowledge has advanced beyond any prediction. Most notably, the emergence of biotechnology – and the associated advances in our basic understanding of biological processes – have vastly changed the toolkit available to plant scientists. Along with these new technologies, changing legal views of intellectual property rights have contributed to significant shifts in the organization of agricultural research. In rich countries, private-sector firms have undertaken large investments in agricultural research based on biotechnology methods.

Against this backdrop, it is reasonable to step back and ask fundamental questions about the role of international crop research. Does varietal improvement still matter? Is public sector research required? Have national systems grown to the point where an international research centre is unnecessary? Have past investments in crop research led to improvements in productivity? Are continuing investments likely to remain worthwhile? Have the international research centres produced anything of value since, say, 1980 (i.e. after the Green Revolution)?¹

Answering questions like these requires a careful methodological approach and lots of data. Fortunately, at the outset of the 21st century, we can draw on more than 40 years of experience with many crop improvement programmes in both IARCs and NARS. This volume represents an attempt to address some of these difficult questions. Specifically,

¹ In this book we define the Green Revolution in a broader context than the popular versions. We include all crops benefiting from conventional crop breeding programmes. We also include periods after 1980.

this volume grows out of a study commissioned by the Standing Panel on Impact Assessment of the Technical Advisory Committee (SPIA-TAC) of the CGIAR. The overall goal of this study was to document the impact of international research on crop genetic improvement in developing countries. The study focused on 11 major food crops: rice, wheat, maize, sorghum, millet, barley, beans, lentils, groundnut, cassava and potato.

This study had five formal objectives:

1. To document the *output* of crop genetic improvement programmes for IARCs, NARS and private firms, where output is measured in terms of the number of officially released crop varieties. This documentation is to include all periods and all regions in developing countries where the crop is important.
2. To evaluate the IARC contributions to crop genetic improvement output. This evaluation calls for varietal content measures identifying the institution responsible for crossing or selecting a released variety and its parents or other ancestors. It also requires statistical estimation of breeding production functions where germplasm (parental material) is explicitly treated as a factor of production.
3. To evaluate the farm production impact of crop genetic improvement products (varieties). This requires evidence of the adoption of varieties by farmers and of the production or productivity advantage of improved varieties over the varieties that they replaced. It also requires consistency between estimates of production advantage at the experimental plot, farm plot and aggregate production levels.
4. To evaluate the IARC programme effects on NARS and private-sector investments in crop genetic improvement programmes. This objective addresses the question of the 'NARS-strengthening' design element in IARC programmes.
5. To evaluate the economic consequences of crop genetic improvement programmes. This requires incorporation of the production advantage estimates from objective 3 into market models (both national and international) enabling the calculation of changes in equilibrium prices, production, trade, consumption and nutrition.

This volume consists of an introductory section (Chapters 2 and 3) and three main parts. Chapter 2 gives an overview which is designed to pick out some recurring themes and central messages from the subsequent chapters, and Chapter 3 offers a survey of methodological issues related to crop improvement studies.

Part II (Chapters 4–16) focuses on studies of individual crops and regions, with each chapter highlighting the experience of a single IARC with a particular crop. Some chapters cover several regions (e.g. Chapter 4 on wheat), while others deal with specific regions (e.g. Chapter 6 on rice in West Africa). The crop studies go into considerable detail on issues such as varietal production, adoption and advantage.

Partly to address the potential bias of the IARC crop-orientated analyses in Part II, this volume also includes three country studies in Part III (Chapters 17–20). These studies examine the impact of international research on productivity in India, Brazil and China. The three country studies directly address the need to have ‘stories’ of research impact that are consistent with national data. These studies essentially begin by measuring productivity increases in agriculture (TFP; total factor productivity). Using econometric techniques, the authors of these chapters then associate TFP gains with national and international crop genetic improvement (CGI) programmes. A disadvantage of the country studies is that they are necessarily unrepresentative. Although India, Brazil and China are good candidates for country studies because they have abundant data, they also have (arguably) the three strongest national agricultural research systems in the developing world. As a result, they are not necessarily typical. Studying these three countries cannot give us a true insight into the relationship between international research and productivity gain in smaller and poorer countries with less research infrastructure.

In order to address the concerns of these smaller countries, Part IV of the book offers three chapters that provide synthetic analysis based on cross-country data. This analysis looks at three issues: the impact of international research on the composition of the varieties grown in developing countries; the impact of international research on production; and the impact of international research on global economic outcomes, using the International Food Policy Research Institute (IFPRI) IMPACT model of the world agricultural economy. The IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) model also makes it possible to consider the effect of international research on social indicators of interest, including poverty and hunger.

The original vision of the builders of the IARCs was dominated by food security concerns and the threat posed by the rapidly expanding population in developing countries. But food security has both global and local dimensions. At a global level, the studies in this volume show that varietal improvement programmes have contributed to what may be regarded as a success story. Food prices have fallen in all countries and consumers have benefited. However, for farmers, it is the local dimension of food security that has mattered most. When prices decline and costs do not, farmers are harmed. Varietal improvement programmes have not delivered modern crop varieties to all farmers and, for many farmers, access to modern varieties is a recent phenomenon. Both biological and political factors contribute to the uneven delivery of improved crop varieties to farmers. CGI programmes should be assessed against both global and local food security dimensions.

It should be noted that many of the chapters in this book – particularly the crop studies – are condensed from larger impact assessments undertaken by the same authors. Some of these assessments have been published as working papers or research centre documents, and readers in search of more detail are encouraged to contact the relevant authors or institutions directly.