



An Assessment of the  
Impact of Agricultural  
Research in South Asia  
since the Green Revolution

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SCIENCE COUNCIL

# An Assessment of the Impact of Agricultural Research in South Asia since the Green Revolution

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## Acronyms and abbreviations

AVRDC	The World Vegetable Center
CGIAR	Consultative Group on International Agricultural Research
CIP	International Potato Center (Centro Internacional de la Papa)
CIMMYT	International Maize and Wheat Improvement Center (Centro Internacional de Mejoramiento de Maiz y Trigo)
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
GIS	geographic information systems
GLASOD	Global Land Assessment of Degredation
GR	Green Revolution
HYV	high-yielding variety
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
ICAR	Indian Council for Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFDC	International Center for Soil Fertility and Agricultural Development (formerly International Fertilizer Development Center)
IFPRI	International Food Policy Research Institute
IGP	Indo-Gangetic Plain
IIFAD	International Institute for Food, Agriculture and Development
ILRI	International Livestock Research Institute
IMT	irrigation management transfer
IPM	integrated pest management
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
LFA	less-favored areas
LISA	low-input sustainable agriculture
NARS	national agricultural research system
NGO	non-governmental organization
NRM	natural resources management
PAANSA	Policy Analysis and Advisory Network for South Asia
PIDE	Pakistan Institute of Development Economics
R&D	research and development
RBF	raised-bed and furrow
RWC	Rice-Wheat Consortium for the Indo-Gangetic Plains
SPIA	Standing Panel on Impact Assessment
SRI	system of rice intensification
SSNM	site-specific nutrient management
TFP	total factor productivity
UDP	urea deep placement
WorldFish	WorldFish Center (formerly International Center for Living Aquatic Resources Management, ICLARM)
ZT	zero tillage

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## Foreword

### Background

The focus of agricultural research by the Consultative Group on International Agricultural Research (CGIAR) and its national agricultural research system (NARS) partners in South Asia in the 1960s and 1970s on food crop technologies, especially staple crop genetic improvement, was driven by the immediate goal of increasing food production and reducing food insecurity. This historical focus on productivity-enhancing technologies in the region has been undeniably successful in achieving the food production goal that guided policy-makers and researchers at the time. There is a considerable literature that documents the large impacts of this research-led productivity growth in the cereal food crop sector in South Asia. This Green Revolution (GR) literature provides the theoretical basis and piecemeal empirical evidence on the associated poverty, food security and social impacts of this technology-driven agricultural growth in the region.

However, the persistence of poverty, hunger and malnutrition despite the evidence of successful productivity effects, which was evident mainly in rice and wheat, has attracted criticism of the research-led agricultural technology revolution in South Asia. Critics blame growing environmental problems on the increased dependency on the external inputs and improved management practices that accompanied productivity-increasing technologies. Also, since the productivity-enhancing technologies targeted two major crops – rice and wheat – and areas with irrigation potential, as well as neglecting the marginal rainfed areas (and crops grown in those areas), the technological revolution of the 1960s and 1970s is criticized as having distributional effects unfavorable to resource-poor farmers. The technological bias towards rice and wheat has also led to changes in the relative prices of different food crops, and this is hypothesized to have negatively affected the traditional diets of local people and over time negatively impacted their health

and nutritional status. While this and other criticisms of the GR and post-GR era have often been made, the evidence to support these claims has not been systematically assembled and evaluated.

Agricultural research by the CGIAR in subsequent decades has tried to address some of these concerns/criticisms by including the goals of reducing poverty, protecting the environment and enhancing the sustainability of natural resources as part of its research strategy. Donors who are critical of the past research strategy in the region are demanding accountability of investments towards these broader CGIAR goals and are concerned that the economic returns to research in the region may have been declining since the 1970s.

### Purpose of the study

This study critically reviews and assesses the large body of evidence on the impacts of agricultural research by the CGIAR and its partners in South Asia. The long history of research, the extensive databases available and the vast literature on impacts that exist in this region provide a fertile ground for this study, which aims to systematically examine and understand the complexities of how research has led to outputs, uptake, outcomes and impacts, and the distributional consequences of these.

The Standing Panel on Impact Assessment (SPIA) was pleased to be able to engage Peter Hazell, a highly respected agricultural economist and researcher with a wealth of experience in agricultural research and development (R&D) and impact assessment, as well as a deep knowledge of the South Asian development and policy experience, to lead this study. The specific terms of reference given to him for this study were the following:

- To provide a systematic assessment of the extent and scope (type, focus, and strategy of research) of CGIAR system investments to date in South Asia (an historical perspective)

- To critically review the literature and systematically summarize: i) the evidence to date of outputs, uptake, influence, outcomes, and impacts of agricultural research (both positive and negative, economic and non-economic) in the region by CGIAR and partner NARS programs and ii) the distributional consequences of research benefits in terms of geographic regions, crop sectors, and types of producers/consumers
- To draw implications and lessons from this synthesis of the literature to address the issues of the gross (positive and negative) and net payoffs from past investments by the CGIAR and partners (the accountability question), as well as to help shape current and future priorities (the institutional learning question)
- To identify knowledge gaps and researchable questions that will improve the understanding of opportunities for, and impediments to, agricultural technology enhancement as a strategy for achieving future CGIAR goals, namely poverty alleviation, food security, and environmental sustainability.

In addressing these terms, SPIA hoped to generate a comprehensive and integrated assessment of the multi-dimensional impacts of CGIAR activities in the region that, ultimately, would provide a better understanding of the direct and indirect pathways of past impacts of CGIAR and partner research on different producer and consumer groups, e.g., rural versus urban, irrigated versus rainfed, resulting from research-led productivity improvements. The intention was to first assemble available information on economic impacts, then to go beyond this benefit-cost calculus into the documented social and environmental impacts in a more systematic manner.

SPIA believes this report goes a long way towards answering those critically important questions and compliments Peter Hazell for conducting a thorough review and analysis and producing a well-written, lucid report. It recommends the report to investors and stakeholders in the CGIAR and to its partners.

## Some insights and inferences from the study

Hazell describes the evolution of priorities for agricultural R&D in South Asia from the time of the GR when ‘food first’ was the imperative and productivity growth in food staples in favored areas was established as the primary goal. This led to a subsequent focus in the 1980s on second-generation priorities such as natural resources management (NRM), the off-site externalities that arose from the intensification associated with the GR, increasing the productivity and quality of high-value crops, trees and livestock, agricultural intensification in many less-favored areas (LFAs) (including foodgrain crops), more precise targeting of the problems of the poor (including enhancing the micronutrient content of food staples), and analysis of policy and institutional options for achieving more sustainable and pro-poor outcomes in the rural sector. The available evidence presented in this report suggests that the national public R&D systems and the CGIAR have responded well to these changing needs, both in terms of their budgetary allocations and the kinds of research they have undertaken.

However, with the current dramatic cereal price increases and disturbingly low global foodgrain stocks leading to another food crisis, one wonders whether we might not be facing a ‘back to the future’ situation, where the priority once again should be to sustainable foodgrain productivity improvement in the more-favored South Asian ecosystems. This is obviously a key strategic question both for the CGIAR and its NARS partners in the region. With the growing numbers and share of urban poor expected in future, there is also a question as to the appropriate future emphasis in R&D strategies on poor smallholder/subsistence farmers with small or no marketable surpluses of foodgrains, versus those farmers with larger marketable surpluses that can exert a more powerful influence on foodgrain prices, which are so critical to the welfare of the urban poor and poor net buyers of foodgrains in rural areas.

Hazell’s analysis of alternative paradigms to the GR approach such as organic farming and low-input sustainable agriculture (LISA) favored by the International Assessment of

Agricultural Knowledge, Science and Technology for Development (IAASTD), indicate that these do not seem to be viable in the favored areas where the GR had its major impact, but may offer more promise in LFAs. The conclusion one can draw from this is that it is unlikely that shifting to such alternative paradigms at this critical juncture as an alternative to the GR approach, as preferred by the IAASTD, would successfully address the current food crisis.

Hazell points out that today agriculture in South Asia is not so significant in the livelihoods of the poor as it was in the GR era. Rural nonfarm revenue is a much more important source of income than previously. This means that agricultural productivity increases from R&D cannot be expected to have the same impact on growth and poverty alleviation as in the 1960s and 1970s, even though it still remains the most attractive win-win public investment opportunity in the region. There is some evidence of this in the declining poverty reduction impacts of rice research investments over the time since the GR era from one study cited by Hazell. While poverty reductions are currently cost-effectively achieved by rice research investments, the cost of raising each person out of poverty is increasing.

The main findings from Hazell's analysis are generally consistent with what is widely known or believed about the GR and post-GR developments, i.e., that agricultural research has continued to provide essential outputs that have helped maintain productivity growth in agriculture, continues to generate high economic rates of return on investments and, indirectly, through the price effects, has contributed to food security and poverty alleviation, both rural and urban. While a number of empirical studies demonstrate the link between agricultural research investments and productivity outcomes, there are few empirical studies that link agricultural research investments to poverty and environmental outcomes. As Hazell points out, apart from needing these kinds of studies to assess the economic value of poverty and environmentally oriented research, they are also needed to better understand the potential tradeoffs and/or complementarities between attainment of productivity, social,

and environmental goals in agricultural research and for determining the kinds of research that offer the best prospects of win-win-win outcomes. While assertions abound about the negative environmental impacts of productivity-enhancing agricultural developments, there are actually few empirical studies that have documented or quantified this effect. Indeed, it is likely that much of the productivity-enhancing research has had positive (but unmeasured) effects in terms of saving millions of hectares of forested land from coming under crop cultivation.

As there are very few impact studies from South Asia that estimate returns to research investments corrected for environmental costs and benefits, or that calculate the research investment cost associated with an observed reduction in the number of poor, Hazell emphasizes the need to develop a set of environmental and poverty indicators that can be used in comprehensive impact assessments; a broader range of indicators, not all of which need to be quantitative, is required.

While SPIA fully concurs with the need to develop robust and relevant social and environmental indicators of the impact of agricultural research, it considers measurable indicators preferable to qualitative ones, as they lend themselves to wider application and aggregation of effects when scaling up. The need for such indicators applies to all types of agricultural research, not only for productivity-enhancing avenues such as food crop genetic improvement research. SPIA is about to commission such a study. Social impacts can include effects on food security, poverty, vulnerability, nutrition, health, education and the overall well-being of society. Environmental consequences can include the effects on the soil, water, wildlife and biodiversity of the local and downstream (and global) environment. Pecuniary and non-pecuniary indicators that capture direct and indirect, positive and negative, and intended and unintended social and environmental impacts will be explored in the SPIA study.

Hazell indicates the need for a holistic household approach to the assessment of the impacts of agricultural research on poverty, due to its complexity. There are

winners and losers from research, both among households within a village and even among members within a household, as well as between rural and urban dwellers and favored versus LFAs. These impacts are also both direct and indirect. SPIA recognizes these complexities and is about to publish a document that provides strategic guidance and a set of good practices in the design and conduct of *ex post* impact assessment studies of agricultural research that covers some of these and other issues. Needless to say, SPIA agrees with Hazell that there remains a need to further document the poverty impacts of agricultural R&D in South Asia, as there are too few quality studies to draw upon.

According to the study, the jury is still out on whether specifically targeting agricultural research to the problems of poor smallholder households and women is paying off in South Asia. It seems clear that agricultural R&D is effective in reducing the numbers of poor people, but its effectiveness in reducing inequalities and inequities is less clear. Other instruments may be preferable to achieve these goals.

## Conclusions

There are many other important insights in the paper that deserve the readers' attention. Space does not allow me to elaborate further here; however, suffice it to say that in general the study has addressed all of the terms of reference, although to varying degrees. Where there was incomplete coverage, this was largely due to the paucity of peer-reviewed literature, to which the author limited his search. It is possible that the grey literature could have supplied additional information, but SPIA concurs with the author's decision to only use quality references. He has identified gaps in the literature as the terms of reference specified and has provided a better understanding and strategic guidance for the CGIAR and its partners in their pursuit of the goals of poverty alleviation, food security, and environmental sustainability in South Asia.

A few issues that deserve more attention than was possible in the present study include:

- The long-term cross commodity effects; e.g., by investing heavily in rice and wheat improvement, did South Asia create a negative bias towards the development of coarse grains, pulses and oil-seeds and did this bias have an adverse impact on the food income and nutritional security of the poorest of the poor?
- The positive and negative impacts of increased productivity in wheat and rice systems beyond higher incomes and food production
- The impacts of improved agricultural technology on different target groups (rural versus urban; irrigated versus rain-fed, etc.).
- The value and desirability of exploiting databases in conducting further impact assessment research to address the impact gaps identified in this study, such as the dearth of studies on crops other than rice, wheat, and maize and on livestock and fish.

We are most grateful to Peter Hazell for agreeing to undertake this study on behalf of SPIA. It is obvious that his wide experience in South Asia enriched his assessment of the literature and led to a most perceptive report that contains many important strategic implications.

Thanks are due to my colleague in SPIA, Mywish Maredia who was the focal point on this study, along with Tim Kelley in the Science Council Secretariat who, along with myself (as SPIA Chair) helped to define the original scope and rationale for the study and also provided guidance and critical feedback at several points throughout its conduct. We also appreciate the two external referees who provided constructive comments and suggestions to the author.

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Jim Ryan

Chair,  
Standing Panel on Impact Assessment  
and Member, Science Council

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## Summary

The Green Revolution (GR) helped transform South Asia. It pulled the region back from the edge of an abyss of famine and led to regional food surpluses within 25 years. It lifted many people out of poverty, made important contributions to economic growth, and saved large areas of forest, wetlands, and other fragile lands from conversion to cropping. The research that underpinned the GR was highly successful in achieving the objectives of the time, and it returned a high rate of economic return. But even as one important research agenda was fulfilled, new problems and challenges arose that required significant evolution of the research and development (R&D) system and its research priorities.

Poverty and malnutrition had not been eliminated, and although poverty shares fell, the number of poor people stubbornly persisted at unacceptable levels. Widespread malnutrition, increasingly in the form of micronutrient deficiencies rather than calorie or protein shortages, also remained. The GR introduced new environmental problems of its own, especially those related to the poor management of irrigation water, fertilizers, and pesticides. Doubts have arisen about the sustainability of intensively farmed systems, and off-site externalities such as water pollution, siltation of rivers and waterways, and loss of biodiversity have imposed wider social costs.

The economic transformation that began to unroll in South Asia as the GR advanced also dramatically changed the context for agricultural R&D. Sustained increases in average per capita income and urbanization led to diversification of national diets with rapid growth in demand for many high-value foods and slow growth in demand for food staples. Agriculture's share in the gross domestic product (GDP) declined steadily, but its share in the workforce declined more slowly, leading to widening income gaps between agricultural and non-agricultural workers. Continued rural population growth also increased the number of small-scale and marginal farmers and many of these are located in less-

favorable areas (LFAs) with low levels of land productivity. Many of the rural poor have diversified their livelihoods to the point where agriculture now plays a relatively small and declining role, a shift that has been facilitated by growth of the nonfarm economy.

In this evolving context, the priorities for R&D have changed from a narrow GR-era focus on the productivity of foodgrains to a need for more work on natural resources management (NRM) and sustainability issues; managing off-site externalities; increasing the productivity and quality of high-value crops, trees and livestock; agricultural intensification in many LFAs; more precise targeting of the problems of the poor, including enhancing the micronutrient content of food staples; and analysis of policy and institutional options for achieving more sustainable and pro-poor outcomes in the rural sector.

The available evidence suggests that the public R&D systems and the Consultative Group on International Agricultural Research (CGIAR) have responded well to these changing needs, both in terms of their budgetary allocations and the kinds of research they have undertaken. Moreover, market liberalization has enabled a more diverse set of agents to engage in agricultural R&D, and private firms and non-governmental organizations (NGOs) have helped ensure that important research and extension needs have not been overlooked.

The results of this changing research agenda have been mixed and are summarized under the headings of productivity, social, environmental, and policy impacts.

### Productivity impacts

The yields of major food crops have continued to grow on average, though sometimes at slowing rates. Crop improvement research has continued to raise yield potentials, as illustrated by the development

of hybrid varieties for most of the major food crops. Breeders have also given greater priority to stabilizing yields through varieties that are more robust to environmental and pest stresses and are genetically more diverse. Farmers have widely adopted improved varieties.

Increased productivity in agriculture still has strong growth linkage impacts on regional and national economic development in South Asia, but these are not so powerful as they were during the GR era. South Asia's economic transformation has led to a more diverse set of engines for national economic growth, and agriculture no longer dominates; even many rural areas are now driven more by urban than by agricultural linkages. However, productivity growth in agriculture is still important for underpinning a good deal of agro-based industry as well as the livelihoods of vast numbers of rural people. It is also necessary for maintaining favorable national food balances, keeping food prices down, and meeting the region's rapid growth in demand for high-value foods.

The economic returns to crop improvement research have remained high and well in excess of national discount rates. Public investments in crop improvement research also give higher returns than most other public investments in rural areas. There is little credible evidence to suggest these rates of return are declining over time.

The CGIAR centers have remained at the forefront of crop improvement research, and large shares of the varieties released by national programs contain improved genetic material obtained from the centers. Impact assessments that attribute some of the benefits from R&D to CGIAR centers also confirm impressive contributions. They show annual benefits in excess of US\$1 billion just from the CGIAR's work on rice, wheat and maize, which is more than enough to cover the costs of the CGIAR's entire global program let alone the \$65 million or so spent in South Asia each year. These kinds of calculations are at best indicative but do suggest that from a narrow productivity perspective the CGIAR's research in South Asia continues to be a sound investment.

## Social impacts

Agricultural research has had mixed impacts on the poor within adopting regions. Impacts vary with the type of technology and the socio-economic conditions in which they are released. Also, because the poor are impacted through a number of different channels (e.g., through changes in their own on-farm productivity, agricultural wages and employment, food prices and local nonfarm opportunities), assessment of net impacts requires a holistic approach at the household level. Now that agriculture plays a smaller role in the livelihoods of the rural poor, agricultural growth may offer weaker benefits for the poor in adopting regions unless it is carefully targeted.

When the impacts of agricultural productivity growth through growth linkages and food prices are taken into account, there is much more consistent evidence that it reduces poverty. Since rural and urban poor people alike spend large shares of their income on food, then their real incomes improve significantly when food prices fall. Aggregate analyses show that public investments in agricultural research have proved very effective in reducing poverty, with more people raised above the poverty line per dollar spent than almost any other public investment in rural areas. Market liberalization may have reduced the power of the growth linkages and food price effects, as suggested by diminishing numbers of poor helped per dollar spent on research in recent years. Even so, the numbers of poor helped each year remain impressive.

Agricultural R&D has been less successful in reducing inter-household and inter-regional inequalities. In adopting regions where R&D has successfully reduced poverty, it has sometimes disproportionately helped richer households and widened income gaps. Also, LFAs that have not been able to benefit from many improved technologies have also been left behind. Spill-in benefits in the form of cheaper foods and improved migration opportunities have helped buffer such inequalities, but they have rarely been sufficient to remove them. Agricultural research is by no means unique in accentuating inequalities while reducing poverty; economic growth in general can have this effect. The solution may lie in

better targeting of agricultural R&D, or with complementary policy interventions (e.g., conditional cash transfers and progressive tax policies) that might be more cost-effective in reducing inequalities.

By generating food surpluses, agricultural R&D has helped overcome widespread malnutrition in South Asia due to insufficient calorie and protein intake. Unfortunately, malnutrition persists, but now more in the form of micronutrient deficiencies, often referred to as 'hidden hunger'. The diversification of diets into higher-value foods, even among the poor, has helped contain this problem, but many poor people are still lacking an adequate diet. Some agricultural R&D has successfully addressed this problem by increasing the productivity of nutrient-rich foods (e.g., fruits, vegetables, and fish) for on-farm consumption and by increasing marketed supplies that have lowered the prices of these products for the poor. However, it has been shown that, on their own, such interventions are often insufficient to overcome hidden hunger among participating households; it is also necessary to provide complementary investments in nutrition education and health services, targeted in ways that empower women with additional spending power.

## Environmental impacts

Considerable research has been directed at the environmental problems associated with agriculture in South Asia. In GR areas, R&D has focused on the problems of sustaining high yields in stressed environments and reducing off-site externality problems. In LFAs, research has focused on ways of reversing resource degradation and sustainably intensifying agricultural production. These problems have attracted a diverse set of NGOs as well as the usual public and international research institutions.

In GR areas, some of the best yields and environmental impacts have been obtained from research on more efficient use of water and fertilizers, and from integrated pest management (IPM) practices. Adapting management practices for irrigation and fertilizer application to align more precisely with the changing needs of plants over their growing period can improve yields,

save water and fertilizer use, and reduce problems with waterlogging, soil degradation and nitrate runoff. IPM does not appear to lead to significant yield gains in South Asia, but it does save on pesticide costs, reduces worker exposure to harmful pesticides, and protects biodiversity. Zero tillage and greater incorporation of organic matter into intensively farmed soils have also proven beneficial. The evidence is much less clear on the benefits of organic farming or the system of rice intensification (SRI), though the contributions of some of SRI's individual management practices for transplanting seedlings, water management, and soil improvement are consistent with other research.

Research on these topics has generated favorable benefit–cost ratios, but the potential benefits have been constrained by adoption levels that are far too small in relation to the scale of the environmental problems to be solved. Major reasons for poor adoption include the higher labor requirements of many improved management practices, high levels of knowledge required of farmers, continued subsidies on water and fertilizer in many South Asian countries, and the externality nature of some environmental problems. These problems are not easily solved through additional technology research, but require complementary changes in government policies and local institutions. Some policy research on these issues has had favorable impacts.

In LFAs, good productivity impacts have been obtained from crop improvement research focusing on plant tolerance of drought and poor soil conditions and resistance to pests and disease. The resulting higher and more stable crop yields enable subsistence-oriented farmers to reduce the area they use to plant food staples, thereby easing pressure on more fragile land. In India, public investments in crop improvement research in many LFAs have generated favorable benefit–cost ratios, sometimes in excess of the ratios obtained from research in many GR areas. Research on watershed development and associated soil and water management issues has contributed to some successful watershed development programs in South Asia. These have been shown to increase agricultural

productivity, reduce soil erosion, and improve groundwater levels. The most successful watershed development projects have strong local participation, usually in the form of a well-managed local organization.

The spread of better technologies and management practices in LFAs has been constrained by poor infrastructure and market access, high labor requirements, the need for farmer training, inadequate property rights, and the need for effective collective action. Some policy research on these issues has had favorable impacts.

### Policy impacts

The economic transformation of South Asia in recent years and the huge success of the GR necessitated some major changes in agricultural policies. With market liberalization, the established role of the state in marketing, storing, and distributing food, providing farm credit and modern inputs, and regulating international trade and agro-industry have all been challenged. The rapid emergence of high-value agriculture and the seriousness of some of the environmental problems associated with agriculture have also required new policy responses. As governments have sought to navigate these turbulent waters, there has been an important opportunity for policy research to help inform the debate.

### Emergent issues

A number of issues have arisen in this study that warrant further attention. These include questions of research policy and measurement issues in impact assessment studies.

### Reaching marginal farmers

Given that agriculture now plays a relatively small part in the livelihoods of many marginal farmers in South Asia, is it still worthwhile to target agricultural R&D to their problems or are there less costly approaches? There are two aspects to this question that need to be considered. First, many more workers will have to exit from

agriculture in South Asia as the economic transformation proceeds. Agriculture's share in the GDP is already much lower than its employment share, implying that the average productivity of agricultural workers is already lower than that of non-agricultural workers. This is reflected in widening per capita income gaps between farm and nonfarm workers and between rural and urban areas. Unless South Asia is to become a much larger exporter of agricultural goods, the gap can only be reduced if the number of agricultural workers declines. This exit is a normal part of the economic transformation of a country, and is driven by increasing opportunities for workers to move to faster growing sectors in manufacturing and services. In this context, investments in large numbers of marginal farmers could simply end up delaying the inevitable, much as happened in Europe during the 20th century.

The second aspect to consider is that, while some types of agricultural research can be targeted at marginal farmers, it would be too expensive to develop technologies that must be tailored to fit with their individual and very diverse livelihood strategies. Further work is needed to identify the kinds of research that can still provide public goods on a sufficiently large scale to justify their cost and which are cost effective compared to alternative ways of assisting marginal farmers. This issue becomes even more pressing as R&D resources are directed at increasing the empowerment and social capital of the poor.

### Food price and growth linkage effects

Has market liberalization and economic growth weakened food price effects and growth multipliers to the point where agricultural R&D can no longer make big reductions in poverty? Lower food prices and growth linkages to the nonfarm economy have played a large role in reducing poverty in South Asia in the past, but may be less important now that food prices are aligned more with border prices and agriculture is a relatively small motor of national economic growth. There is some evidence for this in the form of declining poverty impacts per dollar spent on agri-

cultural research in India, but this is an issue that warrants further study. A related issue stems from the observed decline in total factor productivity (TFP) growth for some crops. This implies that unit production costs are unlikely to fall at the same pace as in the past, leaving less room for future price reductions.

### Impact assessment issues

While far from perfect, the literature contains a wealth of empirical studies that link agricultural research investments to productivity outcomes, with established analytical procedures for calculating rates of returns to investment and benefit–cost ratios. What is lacking is a similar body of empirical studies linking agricultural research investments to poverty and environmental outcomes. Apart from needing these kinds of studies to assess the economic value of poverty and environmentally oriented research, they also help to better understand the potential trade-offs and complementarities between productivity, social, and environmental goals in agricultural research and to determine the kinds of research that offer the best win-win-win outcomes.

There are very few impact studies from South Asia that estimate a return to a research investment corrected for environmental costs and benefits, or which calculate the research investment cost associated with an observed reduction in the number of poor. Many environmental problems cannot be captured through productivity impacts and hence are not so easily quantified. Other studies measure productivity impacts from new technologies, but limit their environmental analysis to qualitative statements about environmental impacts. This may be the most that can realistically be hoped for, and if there were greater agreement on which environmental indicators to use, it would at least be possible to allow for research investments to be ranked in different dimensions. Much the same goes for assessing poverty impacts. While in principle it is possible to convert changes in the distribution of income into a single social welfare measure for benefit–cost analysis, it is generally more practical and insightful to work with a broader range of poverty indicators, not all of which need to be quantitative. Again, agreement on a set of indicators would be helpful for more systematic and comparative ranking of research investments in different dimensions.

# 1. Introduction

The Green Revolution (GR) brought modern science to bear on a widening Asian food crisis in the 1960s. The speed and scale with which it solved the food problem at regional and national levels was remarkable and unprecedented, and it contributed to a substantial reduction in poverty and to launching broader economic growth in Asian countries (Asian Development Bank, 2000).

Although highly successful in achieving its primary food goal, the GR left many poor people and regions behind, an outcome that was aggravated by continuing population growth. While it saved large areas of forest, wetlands, and fragile lands from agricultural conversion, it did not save all and it generated environmental problems of its own, especially ones related to the overuse and mismanagement of modern inputs, the unsustainable use of irrigation water, and the loss of biodiversity within rural landscapes and individual crop species (Asian Development Bank, 2000).

Agricultural research, including the contributions of the Consultative Group on International Agricultural Research (CGIAR), played a key role in developing the technologies that powered the GR (Tribe, 1994; Rosegrant and Hazell, 2000). As a consequence, agricultural research and development (R&D) has been criticized for contributing to the poverty and environmental problems that have continued to plague the South Asian continent. In recent decades, national and international R&D systems have tried to address some of these concerns by including the goals of reducing poverty, protecting the environment, and enhancing the sustainability of natural resources as part of their research strategy. Donors who are critical of the past agricultural research strategy in the region seek accountability of investments towards these broader goals. To this end, this study reviews and assesses a large body of evidence on the impacts of agricultural research by the CGIAR and its partners in South Asia. The study focuses on the post-GR era, which, for the purposes of this

report, is broadly defined to have begun in the early 1980s and extends to the present time.

The post-GR period has seen a dramatic economic and social transformation in South Asia that has redefined the context in which the agricultural R&D systems operate. Understanding this changing context is important for assessing how responsive the CGIAR and the national agricultural research systems (NARS) have been to evolving problems and opportunities, as well as evaluating how effective those responses have been. In Section 2 the report begins with a brief review of this transformation and the ways in which national policy-makers and agricultural R&D systems have responded.

The following sections then review the evidence on the impact of agricultural R&D since the early 1980s. The review draws almost entirely on peer-reviewed and published studies so as to ensure reasonable standards of evidence, and is structured around four key themes.<sup>1</sup> Section 3 assesses the productivity impacts of agricultural R&D; Section 4 assesses social impacts, particularly inequality and poverty impacts; Section 5 assesses environmental impacts; and Section 6 assesses policy impacts. Each section begins with an overview of the main pathways through which impact can occur, which is then followed by a review of the available empirical evidence. Section 7 synthesizes the findings and makes some recommendations for future impact assessment work.

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1 An exhaustive literature search was conducted of published materials using electronic searches of library and journal databases, CGIAR contact persons, and personal contacts.

## 2. The changing context for R&D

### 2.1 An economic and social transformation

The GR enabled South Asia to move from regional food shortages in the 1960s to food surpluses beyond effective demand within 25 years, despite a 70% increase in population. It also contributed to national economic growth, though the pace of national economic growth only really picked up in the 1990s after a period of economic reforms and market liberalization (Rosegrant and Hazell, 2000). Recent years have seen significant growth in national per capita incomes, rapid

urbanization, and economic diversification, with a sharp drop in agriculture's share in national gross domestic product (GDP) (Table 1; Rosegrant and Hazell, 2000). Rising incomes and urbanization have led to rapid diversification of national diets with high growth rates in demand for many high-value foods, particularly livestock products and fruits and vegetables (Joshi et al., 2007; Dorjee et al., 2003). The agricultural sector has continued to grow at respectable rates, as has the sector's total factor productivity (TFP) growth, but both now lag the manufacturing sector (Krishna, 2006).

**Table 1.** Key economic and social indicators for South Asian countries

	Bangladesh	India	Nepal	Pakistan	Sri Lanka
<i>Gross national income/capita (US\$)</i>					
1980–1985	200	290	170	330	380
2006	450	820	320	800	1310
<i>Average growth rate (%)</i>					
GDP, 2000–2006	5.6	7.4	2.7	5.4	4.8
GDP/capita, 2005–2006	4.9	7.7	-0.1	4.1	6.6
Agriculture Value Added, 1990–2005	3.2	2.5	2.9	3.5	1.4
<i>Agriculture GDP share (%)</i>					
1970	54.6	45.2	67.3	36.8	28.3
1990	36.9	31.0	51.6	26.0	26.3
2005–2006	20.0	18.0	35.0	20.0	16.5
<i>Agriculture labor share (%)</i>					
1970	83.5	72.6	94.4	64.6	55.3
1990–1992	66.4	68.1	82.3	48.9	44.3
2001–2003	51.7	Na	Na	45.3	34.7
<i>Urban population share (%)</i>					
1970–1985	17.5	24.3	7.8	29.3	21.4
1995–2001	25.6	27.9	12.2	33.4	23.1
<i>Population growth (%)</i>					
Total (2000–2006)	1.9	1.5	2.1	2.4	0.4
Rural (1990–2005)	1.6	1.4	1.8	2.0	1.1
<i>Poverty (%)<sup>a</sup></i>					
Rural	53.0	30.2	34.6	35.9	27.0
Urban	36.6	24.7	9.6	24.2	15.0
National	49.8	28.6	30.9	32.6	25.0
<i>Irrigated land (% cropland)</i>					
1990–1992	33.8	28.3	43.0	78.5	28.0
2001–2003	54.3	32.7	47.2	81.1	34.4
Growth rate (%), 1990–2005	3.8	1.4	1.0	0.9	2.2

a. The latest poverty data years are: Bangladesh 2000, India 1999/2000, Nepal 2003/04, Pakistan 1998/99 and Sri Lanka 1995/96. Na = not available

Sources: World Bank Indicators and World Bank (2007)

Notwithstanding these generally favorable trends, agriculture and the rural sector remain problematic. Despite out-migration, rural populations and agricultural work forces have continued to grow in much of the region, and the share of the total work force engaged in agriculture remains obstinately high (Table 1). This has led to increasing pressure on land, and the total number of farms has continued to increase, leading to a decline in the average farm size and an increase in the number of small farms of less than 2 hectares (Table 2). Given that agriculture's GDP share is declining much faster than its labor share, the average productivity of the agricultural workforce (measured in GDP/capita) is necessarily falling relative to the productivity of the non-agricultural workforce, leading to widening income gaps between the agricultural and non-agricultural sectors. Poverty, which fell from 59.1% to 43.1% of the population between 1975 and the early 1990s (Asian Development Bank, 2000), remains stubbornly high, especially in rural areas (Table 1).

In this changing context, some of the key challenges that have emerged for agriculture and the rural economy can be summarized as follows:

- The need to diversify agriculture into high-value production to match changing patterns of domestic and export demand. This has required a shift in policy priorities from heavy state interven-

tion in food staples production and national self-sufficiency goals to greater emphasis on high-value market chains and private sector development.

- There are too many small farms of questionable viability and too many workers in agriculture to provide reasonable levels of income parity with the non-agricultural work force. On the other hand, growth in exit opportunities is still too low (see Bhalla and Hazell [2003] for an analysis of the situation in India). Most South Asian countries have yet to reach a tipping point where the absolute number of their agricultural workers begins to decline.<sup>2</sup> Until that happens, agriculture's shares in GDP and employment cannot begin to align, and the income gap between the agricultural and non-agricultural work forces will widen.
- Small farms that cannot diversify into high-value farming have little chance of making an adequate income out of farming. At the same time, market chains have changed, becoming more competitive and integrated and increasingly consumer-driven through the penetration of supermarkets and other large trading firms. These changes have made it harder for small-scale farmers to participate in new growth opportunities and many have been left behind (Joshi et al., 2007).

2 In India there were 226.8 million workers in agriculture in 1980; this increased to 249.2 million in 1990 and 286.8 million in 2000.

**Table 2.** Changes in average farm size and number of small farms

Country	Census year	Average farm size (ha)	Number farms under 2 ha (millions)
Bangladesh <sup>a</sup>	1960	1.70	
	1983/84	0.91	
	1996	0.68	17.800 <sup>c</sup>
India <sup>b</sup>	1971	2.30	49.114
	1991	1.60	84.480
	1995/96	1.40	92.822
Nepal <sup>b</sup>	1992	1.00	2.407
	2002	0.80	3.083
Pakistan <sup>b</sup>	1971/73	5.30	1.059
	1989	3.80	2.404
	2000	3.10	3.814

Source: a. Hossain et al. 2007; b. Nagayets (2005); c. Anriquez and Bonomi (2007)

- The rural poor have diversified their livelihoods and agriculture now plays a relatively small and declining role. Many of the agriculturally dependent rural poor are also concentrated in less-favored areas (LFAs), where gains in agricultural productivity have been slower than elsewhere.
- There has been increasing public awareness of the environmental problems associated with agriculture, and growing demand for improved environmental services such as clean waterways, protection of forest, biodiversity, and sites of natural beauty. These demands often conflict with current agricultural interests. Increasing water scarcities also pose a growing conflict of interest between farmers and the rest of society.

## 2.2 National responses

The Indian experience, reviewed below, typifies the important policy changes that have occurred in most South Asian countries.

The national policy response to the changing agricultural situation in India has been slow compared to the speed with which the government embraced the economic liberalization policies of the early 1990s. Progress has been particularly slow in liberalizing foodgrain markets, including associated agro-industries. This has led many farmers and agro-processing firms to become locked into unprofitable activities, with growing dependence on government price and subsidy supports.

The government has been unable to cut input subsidies for farmers (power, water, fertilizer, and credit). The cost has grown to over Rs. 450 billion per year which, unlike in earlier GR days, is now largely a wasted investment in terms of productivity growth (Jha, 2007). Moreover, the high cost of the subsidies has squeezed out productive public investments in rural infrastructure and R&D, and these have shrunk as a share of total public expenditure (World Bank, 2007).

The large input subsidies on power, water, and fertilizer have also contributed to

environmental damage (e.g., waterlogging and salinization of irrigated lands, fertilizer runoff, high pesticide use) and to the unsustainable use of ground water and worsening water scarcities. The public institutions that provide power and water remain inefficient and have not been adequately reformed, and they are unresponsive to the changing needs of farmers.

Policies towards the high-value sectors have generally been better, and the private sector has been allowed to operate more freely. In value terms, horticultural and livestock products now account for over half India's agricultural output, with most going to the domestic market. Government is active in helping to promote high-value exports, and this will be important for future agricultural growth as domestic high-value markets become saturated. A policy challenge for the high-value sector is linking many more small-scale farmers into these increasingly integrated market chains (Joshi et al., 2007).

The national agricultural R&D system has made several important adjustments over the years. Beginning in the 1980s, the private sector, which had already been active in research on pesticides, fertilizers, and agricultural machinery, began to expand into crop improvement research (Evenson et al., 1999). For example, across Asia, the private sector has captured more than 89% of the maize seed market largely through the production of hybrid rather than open-pollinated varieties (Gerpacio, 2003). This has been facilitated by a national seed policy, which allows importation of seed materials and majority ownership of seed companies by foreign companies. The government also provides tax breaks for private research expenditures and has strengthened intellectual property rights over research products (Pal and Byerlee, 2006). Some non-governmental organizations (NGOs) have also become actively involved, such as the M.S. Swaminathan Research Foundation and the Mahyco Research Foundation.

These changes have led to a much more diverse set of actors and agendas in agricultural R&D, with more focus today on NRM and sustainable agriculture, the problems of LFAs and poor farmers, and

more participatory research approaches. Yet, at the same time, there has been expansion of research capacity in modern science and biotechnology.

In real terms, South Asian countries nearly tripled their public spending on agricultural R&D between 1981 and 2002 (Table 3). Research has also been diversified over the years to reflect the growing diversification of the sector and the importance of environmental and social issues. In 1996–1998, about 35% of the research resources of the Indian Council for Agricultural Research (ICAR) were allocated to crops research, 20% to livestock research, 15% to NRM, and 12% to horticulture. Social science received about 2.5% of total expenditure but 10% of the allocation of total scientists (Pal and Byerlee, 2006). Private sector research expenditure accounts for small shares of total R&D spending in most South Asian countries other than India (Beintema and Stads, 2008).

### 2.3 The CGIAR response

The CGIAR centers have maintained a commodity research focus on productivity growth for South Asia, but with greater attention to sustaining high yields through improved management techniques in GR systems (e.g., the Rice-Wheat Consortium for the Indo-Gangetic Plains [RWC]) and enhancing the nutritional and consumer traits of modern crop varieties (e.g., the Harvest Plus Challenge Program on biofortification). Additionally, a broader research agenda has evolved that includes work on:

- Poverty, gender, and empowerment
- More general environment and NRM

issues, including forest, fish, and biodiversity

- Greater focus on the problems of LFAs
- Agricultural policy.

The CGIAR consistently spends 25–30 % of its total budget on Asia, although it does not report a separate breakout for South Asia (CGIAR Annual Reports). Its research in South Asia is dominated by five centers: the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Rice Research Institute (IRRI), International Maize and Wheat Improvement Center (CIMMYT), International Water Management Institute (IWMI), and the International Food Policy Research Institute (IFPRI). Total CGIAR spending in Asia in 2006 was US\$131 million. Assuming half of this went to South Asia, this would have been about US\$65 million. This is slightly less than half of the combined total budgets of the five centers that do most of the work in the region, and about 3% of total public R&D spending in the region (Table 3). The CGIAR has become a relatively small partner in the region.

### 2.4 Assessing the impact of agricultural R&D

Assessing the impact of agricultural R&D within this rapidly unfolding economic, social, institutional and policy context is complex, much more so than assessing impact during the GR era. First, there are many more dimensions to impact assessment today, not all of which can easily be measured or quantified. In addition to the usual productivity-based approaches, which form the foundation of most benefit–cost and rate of return analyses, there are

**Table 3.** Total public agricultural research expenditures (million 2005 PPP dollars)

	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
1981		396				630
1991	81	746		223	39	1103
1996	82	861	15	188	42	1188
2002	109	1355	26	171	51	1712

Source: Beintema and Stads (2008)

important social (e.g., poverty, inequality, and empowerment) and environmental (e.g., sustainability, ecosystem, and human health) dimensions to consider. There is also a more diverse array of research activity. Crop and livestock improvement work has been the mainstay of most impact assessment work in the past, but much research undertaken since the GR has focused on improved agronomic and NRM practices, environmental management, human nutrition and poverty alleviation. The mix of research players has also changed, leading to more complex interplays between research organizations. Sometimes this leads to collaborative undertakings; sometimes it leads to competition driven by different motives (e.g., private versus public) or conflicting research paradigms (e.g., low or no-input versus GR technologies). The resulting 'contest' of ideas and interventions can lead to healthy enrichment of the technology options available to farmers and to countervailing checks that prevent any one approach from overreaching. But sometimes it leads to misinformation and confusion, as well as misdirection of scarce research resources. In this context, evidence-based research that screens and validates competing paradigms and technologies can also have high social value. Assessing these many dimensions of R&D requires a much broader review of different types of research activities than has been conventional in the past literature on impact assessment.

There are also difficult methodological issues to address. While there are now

standard and quantitative indicators for assessing productivity impacts, there is much less consensus on how to measure poverty and environmental impacts and less opportunity for establishing broadly accepted quantitative indicators. Additionally, it is difficult to establish relevant counterfactuals for assessing impacts when dynamic demographic and market forces are also impacting on poverty and inequality and adding to pressures on the environment. Given the long lead times inherent in bringing agricultural research to fruition and in realizing environmental benefits, much agricultural research must be assessed in a long-term framework and against goals and market and social contexts for which it was not necessarily designed. There are also difficult issues to address when the impact of new technologies is to be attributed to specific institutions like CGIAR centers. Best practice guidelines need to be followed:

- Using an adequate counterfactual situation
- Controlling for other relevant factors that drive change besides R&D
- Allowing for the long lead times characteristic of much agricultural R&D
- Using credible impact measures for social and environmental outcomes
- Evaluating investments against goals made at the time they were initiated, as well as against eventual outcomes.

Given these kinds of difficulties, the review that follows draws primarily on peer-reviewed publications, whose methods are most likely to meet best practice guidelines.

## 3. Productivity impacts

### 3.1 Productivity impact pathways

Given the large populations to be fed in the face of growing resource scarcities, improving agricultural productivity has consistently remained one of the main objectives of agricultural R&D in South Asian countries.

The most direct way in which R&D can impact on productivity is through yield levels and yield variability. But other pathways are also important. Crop improvement research can shorten growing periods and reduce plant sensitivity to day-length, both of which enable more crops to be grown on the same land each year. Research on labor-saving technologies such as mechanization and herbicides can increase labor productivity, freeing up labor for other income-generating activities. Research on NRM, including water management, can enhance as well as sustain the productivity of key natural resources.

Productivity growth in agriculture can also have far-reaching impacts on the productivity and growth of regional and national economies. There are several growth linkages that drive this relationship:

- Benefits from lower food prices for workers
- More abundant raw materials for agro-industry and export
- Release of labor and capital (in the form of rural savings and taxes) to the non-farm sector
- Increased rural demands for non-food consumer goods and services, which in turn support growth in the service and manufacturing sectors.

There is a substantial and compelling empirical literature on these productivity impacts, the evidence for which is reviewed below in descending order from macro to micro impacts. The productivity impacts of improved NRM research are largely taken up in Section 5 because they are also important for environmental sustainability.

### 3.2 Evidence on economy and sector-wide impacts

The powerful economy-wide benefits emanating from technologically driven agricultural growth were amply demonstrated during the GR era in South Asia (Mellor, 1976). In India, the fact that the non-agricultural share of total national employment did not change for over a century (until the full force of the GR was underway in the 1970s) provided strong circumstantial evidence of the importance of agricultural growth as a motor for the Indian economy. This was also confirmed by Rangarajan (1982) who estimated that a one percentage point addition to the agricultural growth rate stimulated a 0.5% addition to the growth rate of industrial output, and a 0.7% addition to the growth rate of national income.

Regional growth linkage studies have also shown strong multiplier impacts from agricultural growth to the rural nonfarm economy (Hazell and Haggblade, 1991; Hazell and Ramasamy, 1991). The size of the multipliers vary depending on the method of analysis chosen, and for South Asia they vary between US\$0.30 to US\$0.85 – i.e., each dollar increase in agricultural income leads to an additional US\$0.30–0.85 increase in rural nonfarm earnings (Haggblade et al., 2007). The multipliers tend to be larger in GR regions because of better infrastructure and market town development, greater use of purchased farm inputs, and higher per capita incomes and hence consumer spending power (Hazell and Haggblade, 1991).

As South Asian economies have grown and diversified, other important engines of growth have emerged at national and regional levels. In India, for example, national economic growth has accelerated to new highs in recent years even as agricultural growth has slowed. In many rural areas, the correlation between agricultural growth and growth of nonfarm income and employment has also become weaker (Harriss-White and Janakarajan, 1997; Foster and Rosenzweig, 2004). There is also

evidence that the fastest growth in the rural nonfarm economy is occurring in areas linked to major urban centers and transport corridors, regardless of their agricultural base (Bhalla, 1997).

This is not to say that agricultural growth is now unimportant. Agriculture's contribution to national GDP is higher than ever in absolute terms; it is only less important in relative terms. Moreover, large shares of the working population are still primarily engaged in agriculture, as are most of the poor. Continued growth in agricultural productivity is needed to maintain favorable national food balances, meet rising demands for high-value foods including livestock products, and raise the living standard of those workers and poor people remaining in agriculture and rural areas.

#### **Economic impact of aggregate R&D investments**

Several studies have attempted to measure the economic returns that can be attributed to total public investments in agricultural research. These studies invariably estimate changes in TFP and the share of that change that can be attributed to agricultural R&D investments. Evenson et al. (1999) identified 10 *ex post* studies of the returns to aggregate research programs in South Asia. Seven of these, plus a more recent study by Thirtle et al. (2003), extend into

the post-GR era and are summarized in Table 4. Despite some differences in methods of analysis and time periods covered, all the studies show rates of return that are much higher than any reasonable discount rate.

Fan et al. (2000b) used a simultaneous-equations model to estimate the returns to public investments in agricultural R&D in India. In addition to controlling for other types of public investments (necessary to avoid biasing the estimated returns to research), this approach has the added advantage of giving comparative returns between different types of public investment. They found that public investment in agricultural research yielded the highest productivity return in recent decades, with a benefit–cost ratio of 13.5 (Table 5). This is more than double the benefit–cost ratio for the next best public investment – rural roads, and more than 10 times the ratios for education, irrigation, and rural development.

Fan et al. (1999) also found that the marginal benefits of R&D investment in India show little sign of diminishing over time, unlike some other public investments. This is confirmed by Evenson et al. (1999) in a study of the determinants of growth in India's agricultural TFP from 1956 to 1987.

**Table 4.** Estimated internal rates of return to agricultural research in South Asia

Study	Country	Period	Rate of return (%)
Nagy (1985)	Pakistan	1959–1979	64
Khan and Akbari (1986)	Pakistan	1955–1981	36
Evenson and McKinsey (1991)	India	1958–1983	65
Dey and Evenson (1991)	Bangladesh	1973–1989	143
Azam et al. (1991)	Pakistan	1956–1985	58
Evenson and Bloom (1991)	Pakistan	1955–1989	65
Rosegrant and Evenson (1992)	India	1956–1987	62
Evenson et al. (1999)	India	1977–1987	57
Thirtle et al. (2003)	South Asia <sup>a</sup>	Various years 1985–1995	24

a Includes Bangladesh, India, Nepal, Pakistan, and Sri Lanka

**Table 5.** Productivity and poverty effects of government investments in rural India, 1993

Expenditure variable	Productivity returns in agriculture in rupees (Rs) per rupee invested	Number of people lifted out of poverty per million rupees invested
R&D	13.45	84.5
Irrigation	1.36	9.7
Roads	5.31	123.8
Education	1.39	41.0
Power	0.26	3.8
Soil and water	0.96	22.6
Rural development	1.09	17.8
Health	0.84	25.5

Source: Fan and Rao (2008)

### 3.3 Evidence on commodity-wide impacts

#### Cereals

The spread of modern cereal varieties in recent decades and their enormous contribution to the growth in food production throughout South Asia has been widely documented (Evenson and Gollin [2003] provide a comprehensive assessment).

Adoption rates continue to rise (Tables 6 and 7), and modern varieties are continually being improved and replaced (Lantican et al., 2005; Evenson and Gollin, 2003). CGIAR-related germplasm continues to be used extensively by national breeding programs in South Asia (Evenson and Gollin, 2003). For example, over 90% of the wheat varieties now grown in South Asia contain CIMMYT-related germplasm (Lantican et al., 2005).

**Table 6.** Percentage of harvested area under modern varieties in South Asia

	Rice	Wheat	Maize
1965	0.0	1.7	0.0
1970	10.2	39.6	17.1
1975	26.6	72.5	26.3
1980	36.3	78.2	34.4
1985	44.2	82.9	42.5
1990	52.6	87.3	47.1
1995	59.0	90.1	48.8
2000	71.0	94.5	53.5

Source: Gollin et al. (2005)

**Table 7.** Percentage of planted area under improved sorghum and millet varieties

Country	Year	%
<i>Sorghum</i> <sup>a</sup> India	1966	1.0
	1971	4.1
	1976	15.4
	1981	23.3
	1986	34.5
	1991	54.8
	1998	71.0
Pakistan	1995–1996	21.0
<i>Millet</i> <sup>b</sup> India	1995–1996	65.0

a. Deb et al. (2005b) and Deb and Bantilan (2003)

b. Bantilan and Deb (2003)

Yields of wheat and rice have continued to rise on average across South Asia, but despite continuing improvements in crop varieties (e.g., the recent release of hybrid rice), annual growth rates are slowing (Table 8). This is confirmed by more careful micro-based studies of wheat and rice yields in the Indo-Gangetic Plain (IGP) (Murgai et al., 2001; Ladha et al., 2003; Cassman and Pingali, 1993; Bhandari et al., 2003) and in India's major irrigated rice-growing states (Janaiah et al., 2005). There are several possible reasons for this slowdown: displacement of cereals on better lands by more profitable crops like groundnuts (Maheshwari, 1998); diminishing returns to modern varieties when irrigation and fertilizer use are already at high levels; and the fact that foodgrain prices have until recently been low relative to input costs, making additional intensification less profitable. But there are concerns that the slowdown also reflects a deteriorating crop-growing environment in intensive monocrop systems. Ali and Byerlee (2002) and Murgai et al. (2001), for example, report deteriorating soil and water quality in the rice–wheat system of the IGP, and Pingali et al. (1997) report degradation of soils and buildup of toxins in intensive paddy (irrigated rice) systems.

These problems are reflected in growing evidence on stagnating or even declining levels of TFP in some of these farming systems (e.g., Janaiah et al., 2005). Ali and

Byerlee (2002) have shown that degradation of soil and water are directly implicated in the slowing of TFP growth in the wheat–rice system of the Pakistan Punjab. Ladha et al. (2003) examined long-term yield trials data at multiple sites across South Asia and found stagnating or declining yield trends when input use is held constant. One consequence has been that farmers have had to use increasing amounts of fertilizers to maintain the same yields over time (Pingali et al., 1997). There is also concern that pest and disease resistance to modern pesticides now slows yield growth, and that breeders have largely exploited the yield potentials of major GR crops – though sizeable gaps still remain between experiment-plot and average farmer yields. We return to these issues in Section 5.

Growth in sorghum yields has also slowed, but the yields of maize and millets have accelerated in recent years (Table 8). In the case of maize, the rapid spread of hybrids since the 1980s has added significantly to yields. Singh and Morris (2005) estimated that without hybrid maize, India's annual maize production would be about one million tons (or 10 %) less each year. Growth in millet yields accelerated in recent years because improved varieties were only developed and released in the 1980s, and are still spreading (Bantilan and Deb, 2003).

Not all of this progress can be credited to agricultural research. Nevertheless,

**Table 8.** Annual growth rates for crop yields; major producing countries and South Asia average (% per year)

Crop/country	1961–1970	1971–1980	1981–1990	1991–2000	2001–2005	1961–2005
<i>Rice</i>						
Bangladesh	0.43	2.45	2.67	2.67	2.27	1.97
India	1.14	1.64	3.59	1.08	0.85	1.95
South Asia	1.15	1.78	3.20	1.46	1.17	1.94
<i>Wheat</i>						
India	4.46	1.87	3.11	1.82	-0.98	3.05
Pakistan	3.82	3.49	1.62	2.60	2.64	2.65
South Asia	4.27	2.31	2.67	2.03	-0.22	2.95
<i>Sorghum</i>						
India	0.54	5.09	1.76	-0.05	0.05	1.38
South Asia	0.58	4.90	1.71	-0.05	0.08	1.35
<i>Millet</i>						
India	2.02	1.59	2.00	2.04	6.03	1.90
South Asia	1.94	1.54	1.89	2.01	5.89	1.84
<i>Maize</i>						
India	1.67	1.36	2.52	2.54	1.01	1.73
Pakistan	0.63	1.30	1.29	2.99	15.90	1.63
South Asia	1.69	0.90	2.33	3.51	10.63	2.14
<i>Groundnut</i>						
India	0.34	0.93	1.20	0.56	4.37	1.10
South Asia	0.46	0.90	1.17	0.57	4.17	1.08
<i>Chickpea</i>						
India	3.82	-1.38	0.22	0.8	2.90	0.18
Pakistan	1.46	0.34	-0.42	3.88	1.42	1.03
South Asia	-0.80	-4.11	2.28	4.86	2.98	0.14
<i>Potato</i>						
India	2.17	3.71	2.21	1.54	-1.52	2.39
Nepal	0.63	-0.73	2.84	0.90	3.62	1.56
Pakistan	2.65	-0.44	-0.37	4.29	2.74	1.35
South Asia	2.78	3.14	1.88	1.56	-0.69	2.23

Source: Calculated from FAOSTAT (<http://faostat.fao.org>)

estimates of the economic value of crop improvement research in South Asia are consistently high (Evensen and Gollin, 2003). Table 8 summarizes the rates of return estimated for a range of commodities as found in studies published since 1985.

Rates of return range from 20% to 155% and average 60%. They are also consistent with the high average returns reported in the literature for all Asia: Evenson (2001) reported an average rate of return of 67% and Alston et al. (2000) reported an average rate of 49.6% (median 78.1%). Alston et al. (2000) and Evenson et al. (1999) found no evidence that rates of return are declining over time.

Going beyond rate of return calculations, Fan (2007) estimated that India's rice variety improvement work contributes about US\$3–4 billion per year to national rice production in constant 2000 prices, considerably greater than the total annual cost of the national R&D system (Table 3). Using some plausible and alternative attribution rules, Fan also estimated that IRRI's rice improvement work can be credited with between 12% and 64% of India's US\$3.6 billion gain in 2000 (i.e., a gain of between US\$432 million and US\$2304 million), and with 40–80% of the US\$3.9 billion gain in 1991 (i.e., a gain of between US\$1560 million and US\$3120 million). He notes that IRRI's contribution has diminished since

**Table 9.** Estimated internal rates of return to crop improvement research in South Asia

Study	Country	Commodity	Period	Rate of return (%)	Benefit-cost ratio
Nagy (1985)	Pakistan	Maize Wheat	1967–1981	19 58	
Morris et al. (1992)	Nepal	Wheat	1966–1990	37–54	
Evenson and McKinsey (1991)	India	Rice Wheat Jowar (Sorghum) Bajra (Pearl millet) Maize	1954–1984	155 51 117 107 94	
Byerlee (1993)	Pakistan	Wheat	1978–1987	22	
Azam et al. (1991)	Pakistan	Wheat Rice Maize Pearl millet Sorghum	1956–1985	76 84 45 42 48	
Collins (1995)	Pakistan	Wheat		60–71	
Iqbal (1991)	Pakistan	Rice	1971–1988	50–57	
Byerlee and Traxler (1995)	South Asia	Wheat (spring bread)		91	
Hossain (1998)	Bangladesh	Rice	1973–1993		16.6
Joshi and Bantilan (1998)	India	Groundnuts (improved variety plus RBF)		13.5–25.2	2.1–9.4
Bantilan and Joshi (1996)	India	Pigeonpea (wilt resistance)	1986–2005 <sup>a</sup>	61	
Ramasamy et al. (2000)	India	Pearl millet	1970–2000 <sup>a</sup>	27	
Mittal and Kumar (2005)	India	Wheat	1976–1980 1986–1990 1991–1995	65.5 67.8 61.1	

a. Projected beyond historical data. RBF = raised bed and furrow

1991 but is still far more each year than is needed to justify the institute's entire research budget. Indeed, in both years it was enough to cover the annual cost of the CGIAR's entire global program!

Lantican et al. (2005) estimated that the additional value of wheat production in developing countries attributable to international wheat improvement research ranges from US\$2.0 to US\$6.1 billion per year (2002 dollars). They did not provide a regional allocation of these benefits, but assuming that benefits are shared in rough proportion to the share of the world wheat

area grown<sup>3</sup>, South Asia captures about 28% of the benefits, or US\$560–1710 million per year. Similarly, Morris et al. (2003; p.156) estimated that the economic benefits to the developing world from using CIMMYT-derived maize germplasm fall in the range of US\$557–770 million each year. Again they do not provide a regional allocation of these benefits, but assuming that benefits are shared in rough proportion to the world share of the area

3 This may overstate the benefits to South Asia, since the share of the area planted to wheat varieties with CIMMYT germplasm is lower for all Asia than for the rest of the developing world (Lantican et al., 2005).

grown, South Asia captures about 8% of the total benefits, or US\$45–62 million per year.

### **Stability of cereal production**

Modern cereal varieties were developed to give higher yields in favorable environments, such as irrigated areas with high fertilizer usage. This led to some initial concern that they would be more vulnerable to pest and weather stresses than traditional varieties, increasing the risk of major yield and food production shortfalls in unfavorable years. Early work by Mehra (1981) among others suggested that yield variability for cereals in India was increasing relative to increases in average yield (higher coefficients of variation) at the national level, raising the specter of a growing risk of national food shortages and high prices in some years. Subsequent analysis showed that at the plot level, many modern varieties were no more risky than traditional varieties in terms of downside risk,<sup>4</sup> and that while some crop yields measured at regional and national levels were becoming more variable (a bigger problem for maize and other rainfed cereals than for wheat or rice<sup>5</sup>), this was largely the result of more correlated or synchronized patterns of spatial yield variation (Hazell, 1982, 1989). Several scholars suggested that these changes might be attributable to the widespread adoption of more input-intensive production methods that led to larger and more synchronized yield responses to changes in market signals and weather events, shorter planting periods with mechanization, and the planting of large areas to the same or genetically similar crop varieties (e.g., Hazell, 1982; Ray, 1983; Rao et al., 1988). Later studies showed that rice and wheat yields generally became more stable in South Asia in the 1990s, but the patterns for maize and coarse grains were more mixed, especially at country and sub-regional levels (Sharma et al., 2006; Chand and Raju, 2008; Gollin, 2006; Larson et al., 2004; Deb and Bantilan, 2003; Singh and Byerlee, 1990).

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4 See relevant case study material in Anderson and Hazell (1989).

5 In contrast to India, Tisdell (1988) found that relative yield and production variability of foodgrain fell at district and national levels in Bangladesh over a similar time period.

National yield and production variability are less of a policy issue today, given that international trade can play a bigger role in stabilizing market supplies and prices. But since large areas of major cereals are still planted to relatively few modern varieties, concern remains about the risk of possible genetic uniformity, making crops vulnerable to catastrophic yield losses from changes in pests, diseases, and climate. The famine that was triggered by potato blight in Ireland in the 19th century is often cited as an historical example of society's vulnerability to a narrow genetic base in food crops. As early as 1786, colonial officers on the Asian subcontinent recorded the devastation and hunger caused by epidemics of rust disease in wheat. According to such records, wheat landraces in India, to which millions of hectares were planted, were highly susceptible to rust disease (Howard and Howard, 1909). The hunger and starvation associated with these events was aggravated by the absence of any serious relief efforts at the time, and hence would be less likely to occur today. Apart from a few isolated incidents, mostly outside the South Asian continent (e.g., southern corn leaf blight – *Helminthosporium maydis* – in the US in 1970 and the vulnerability of IR 8 rice to brown plant hopper in Southeast Asia), there has not been a recorded catastrophe in production of major food crops in modern times.

The absence of any catastrophic crop failures is due in large part to extensive behind-the-scenes scientific work to prevent such disasters. Crop genetic uniformity has been counteracted by spending more on conserving genetic resources and making them accessible for breeding purposes; through breeding approaches that broaden the genetic base of varieties supplied to farmers<sup>6</sup>; and by changing varieties more frequently over time in order to stay ahead of evolving pests, disease and climate risks (Smale et al., forthcoming). These measures reflect the growing

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6 Work with molecular markers shows that at the molecular level, the amount of diversity present within CIMMYT-bred wheat materials has risen steadily over time, and the newest CIMMYT lines show similar levels of diversity to landraces (Lantican et al., 2005). The steady increments in diversity reflect the increasing use by CIMMYT wheat breeders of varieties and advanced lines derived from multiple landraces and synthetic wheats.

strength of national breeding and genetic conservation programs, as well as the backup and support provided by CGIAR centers. For example, the CGIAR centers have contributed to the buildup and characterization of germplasm banks for South Asian crops and have facilitated access to genetic materials from other parts of the world. They also spend significant shares (estimated at between 33% and 50% for the commodity centers) of their budgets on 'maintenance' research in order to provide national systems with new germplasm on a timely basis in response to emerging new pest, disease and climate risks (Smale et al., forthcoming<sup>7</sup>).

### Oilseeds

Demand for vegetable oils has grown rapidly in South Asia since the GR. In India, a growing share of this demand has needed to be met by imports because domestic production could not keep pace. Yield growth has accelerated in recent years (Table 8) and the area planted to oilseeds has also increased. In some areas, oilseeds are now more profitable than cereals on irrigated land (e.g., Maheshwari, 1998).

In India, groundnut is the main oilseed crop, and ICRISAT has worked with the Indian NARS to develop improved varieties that are higher-yielding and more resistant to disease, pests, and drought. Deb et al. (2005a) found that improved varieties have been widely adopted in the main groundnut-producing states of India, and that in many cases yields have increased by 50–100%. Compared to the best-performing local varieties, the improved varieties also have 20–30% lower per-ton production costs and per-hectare returns that are at least 50% higher. The net economic return to the groundnut improvement research is not calculated.

Joshi and Bantilan (1998) have assessed the economic returns to an ICRISAT-promoted groundnut technology package that involves improved varieties plus improved

agronomic practices built around a raised-bed and furrow (RBF) concept. This package was widely adopted in the state of Maharashtra during the early 1990s and by 1994 was applied to 47,000 hectares, or about 31% of the total groundnut area. Improved groundnut varieties grown without the full RBF package were also adopted on 83% of the cropped area. The full technology package led to average yield gains of 38%. It also proved profitable and average net income increased by 70% per hectare. Taking into account the full costs of the research program incurred by ICRISAT and its Indian partners in developing the RBF package, the benefit–cost ratio is estimated at between 2.1 and 9.4 (with internal rates of return between 13.5% and 25.2%) over the 1974–2005 period, depending on assumptions about the extent of adoption of key components of the technology package. The lion's share of the economic gains is estimated to be captured by farmers, with less than 20% accruing to consumers through lower groundnut prices.

### Pulses

Pulses are important leguminous protein-rich crops. Grown mostly under nonirrigated conditions, they are important to the poor. The area planted to pulses stagnated or declined with the spread of high-yielding cereal technologies because there were no comparable improvements in pulse technologies at the time. Yields have since increased but the gains tend to be crop-specific. Chickpea yields, for example, have picked up in recent years in South Asia (Table 8), but in India, yields of most other pulses grew by less than 1% per year during the 1990s, and TFP growth fared little better (Joshi and Saxena, 2002). Research targeted at pulses has led to improved varieties – India alone released 92 improved pulse varieties during the Eighth Plan period (Ramasamy and Selvaraj, 2002) – but there has been only modest impact at aggregate levels. Nevertheless, there have been smaller scale successes.

Joshi et al. (2005a) report a more than doubling of chickpea production in Andhra Pradesh between 1980 and 1995 (to 36,000 tons), driven by higher yields (up 247%) and an increased crop area. The adoption of improved varieties developed

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7 Ongoing efforts to contain the spread of Ug99, a new race of stem rust (*Puccinia graminis tritici*) in wheat that emerged in Uganda in 1999 and has spread to wheat-growing areas of Kenya and Sudan and now threatens Asia is a good example of payoff from genetic conservation and maintenance research (Wanyera et al., 2006).

by ICRISAT played an important role in this expansion.

Shiyani et al. (2002) assessed the impact of two of ICRISAT's improved chickpea varieties in a poor tribal area in Gujarat, India. The two improved varieties (ICCV 2 and ICCV 10) were selected from a range of existing ICRISAT varieties using participatory methods. The improved varieties spread quickly, and based on a farm survey, Shiyani et al. (2002) found that they increased yields over the traditional variety by 55% for ICCV 10 and 34% for ICCV 2. Both varieties reduced unit costs of production, and net returns per hectare increased by 84% for ICCV 10 and 68% for ICCV 2. Both varieties also doubled labor productivity and reduced the variability of yields. An analysis of adoption patterns shows significantly greater adoption among small-scale farmers than larger-scale farmers.

Bantilan and Joshi (1996) assessed the impact of a wilt-resistant variety of pigeonpea (ICP 8863) developed by ICRISAT and partners in the 1980s. Wilt is a major problem in Karnataka, considered the pigeonpea granary of India, and nearby growing areas in Andhra Pradesh, Maharashtra, and Madhya Pradesh. Together, these areas grew 1,280,000 hectares of pigeonpea in 1990. The improved variety not only provided wilt resistance, but also raised yields by 57% and reduced production costs per ton by 45%. Although released in the late 1980s, it had been adopted on 60% of the crop area by 1992/93. Taking account of the research costs of ICRISAT and its partners, the internal rate of return was estimated at 61%.

Mungbeans are one of the more important pulses grown in Pakistan, and about 90% of the crop is grown in the Punjab. Improved varieties were developed by the NARS and The World Vegetable Center (AVRDC) that are high-yielding, pest-resistant, fast-growing and have good consumption characteristics. These varieties were released in the early 1980s (Ali et al, 1997). Ali et al. (1997) have assessed the economic impact of the improved mungbean varieties based on a farm survey conducted in the Pakistan Punjab in 1994. They report that adoption was rapid and widespread: Desi, the main traditional variety, was grown by 80% of farmers in 1988 but by only 10% in 1994. At the same time, the area planted to mungbeans increased from about 100,000 hectares to 167,900 hectares, and their importance in total pulses increased from 3% in 1980 to 11% in 1993/94. Modern varieties raised yields by 45% and per-hectare profit by 240%. Because mungbeans are grown in rotation with wheat each year (over two cropping seasons), they also had residual impact on wheat yields and reduced the need for nitrogen fertilizer by about 45%. Using a consumer and producer surplus approach and also taking account of the benefit to wheat production, Ali et al. (1997) estimated the net social benefit of the improved varieties to be US\$20 million, or US\$119 per hectare of mungbeans grown in 1993/94. They did not estimate the research costs incurred in developing the varieties.

### Potatoes

Growth in potato yields has slowed in recent years for South Asia, mainly because of slowing yield growth in India,

**Table 10.** Potato adoption area in South Asia, 2007 (ha)

Country	CIP distributed, NARS released	CIP cross, NARS selected	NARS cross, CIP progenitor	Total CIP—NARS partnerships	% total planted area
Bangladesh		5595		5595	1.47
India			43,016	43,016	3.11
Nepal	35,842			35,842	19.60
Pakistan					0.00
Total	35,842	5595	43,016	84,453	4.11

Source: Unpublished data provided by Graham Thiele, International Potato Center (CIP)

the largest producing country in the region (Table 8). International Potato Center (CIP)-related breeding material has yet to widely penetrate the region and was planted on only 4.1% of the potato area in 2007 (Table 10), despite an earlier study showing favorable impacts on yields and per hectare returns (Khatana et al., 1996). Khatana et al. (1996) also calculated a projected rate of return of 33% to CIP's research in India, but this must now be downgraded because of adoption has been much slower than was projected at the time of the study.

### **Other commodities**

The rapid growth of high-value agriculture in South Asia in recent years has led to a substantial increase in agricultural research targeted to high-value commodities. As noted earlier, the private sector has expanded rapidly into these markets and from 1996 to 1998, ICAR – the Indian NARS – spent about one-third of its total budget on livestock and horticulture research.

The real growth in livestock production in South Asia since 1980 has been in poultry, eggs, and dairy production. The only involvement of the CGIAR centers has been in research on policy and marketing issues, and on increasing feed supplies. The International Livestock Research Institute (ILRI), ICRISAT, and ICAR have been working jointly to develop dual-purpose varieties of sorghum and millet that have more nutritious straw for feeding to ruminants. An *ex ante* assessment using geographic information systems (GIS) to identify potential adoption areas and a feed–animal performance simulation model to estimate

production impacts yielded an estimated present-day value of net benefits over 10 years of US\$42 million, an expected benefit–cost ratio of 15 and an internal rate of return of 28% (Kristjanson et al., 1999). The research is ongoing and hence has not yet been subjected to an *ex post* assessment.

The CGIAR centers have undertaken some work on vegetables and fruits within the context of nutrition and biodiversity conservation (e.g., Bioversity International's work on *in-situ* conservation), but these are not likely to have had major productivity impacts. AVRDC is a more important player in South Asia, and has contributed to productivity-enhancing research in Bangladesh. In an assessment of that work, Ali and Hau (2001) show high on-farm returns during the 1990s, improved nutrition outcomes and an internal rate of return of 42% to the cost of AVRDC's research investment. However, due to the small scale of the work, the net benefits to the country were only about US\$1 million per year.

WorldFish (formerly ICLARM) has developed genetically improved strains of Nile tilapia for on-farm production and has extended these to farmers in six Asian countries, including Bangladesh. An assessment of on-farm trials by Deb and Dey (2006) showed yield gains of 78% in Bangladesh, achieved without any increase in production costs. Using economic surplus methods, Deb and Dey (2006) quantified the benefits from – and costs of – research and dissemination by WorldFish and its partners in all six countries and obtained an internal rate of return of 70.2%.