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

August 2008

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

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

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Contents

Tables

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
LFAs	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 oilseeds 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 rainfed, 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.

Finally we thank Green Ink for editing and producing this report for publication.

Jim Ryan

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

1 June, 2008

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-favored 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 nonagricultural 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 agricultural 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 tradeoffs 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.[1] 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.

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
Gross national income/capita (US$)					
1980–1985	200	290	170	330	380
2006	450	820	320	800	1310
Average growth rate (%)					
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
Agriculture GDP share (%)					
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
Agriculture labor share (%)					
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
Urban population share (%)					
1970–1985	17.5	24.3	7.8	29.3	21.4
1995–2001	25.6	27.9	12.2	33.4	23.1
Population growth (%)					
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
Poverty (%)[a]					
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
Irrigated land (% cropland)					
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 intervention 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.[2] 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[a]	1960	1.70	
	1983/84	0.91	
	1996	0.68	17.800[c]
India[b]	1971	2.30	49.114
	1991	1.60	84.480
	1995/96	1.40	92.822
Nepal[b]	1992	1.00	2.407
	2002	0.80	3.083
Pakistan[b]	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[a]	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	%
Sorghum[a]		
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
Millet[b]		
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
Rice						
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
Wheat						
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
Sorghum						
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
Millet						
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
Maize						
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
Groundnut						
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
Chickpea						
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
Potato						
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 [a]	61	
Ramasamy et al. (2000)	India	Pearl millet	1970–2000 [a]	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[3], 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,[4] 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[5]), 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 subregional levels (Sharma et al., 2006; Chand and Raju, 2008; Gollin, 2006; Larson et al., 2004; Deb and Bantilan, 2003; Singh and Byerlee, 1990).

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[6]; 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

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[7]).

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

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%.

4. Social impacts

4.1 Poverty impact pathways

The primary goal of agricultural research during the GR era was to increase food production. Historically, this led to a focus on foodgrains in high-potential areas where the quickest and highest returns to R&D could be expected. This strategy was extremely successful in achieving its primary goal in South Asia. Additionally, it helped cut poverty in the region during the 1970s and 1980s – from 59.1% of the population in 1975 to 43.1% in the early 1990s (Rosegrant and Hazell, 2000). But it did not eliminate poverty or malnutrition, and today, despite the fact that most South Asian countries now have plentiful national food supplies, poverty is still a major problem. About 450 million South Asians currently live below the US$1 per day poverty line (about the same as in 1975), and 80% of these are rural and obtain at least part of their livelihood from agriculture and allied activities (World Bank, 2007; Ahmed et al., 2008). The agricultural research systems have responded to this problem by targeting more of their research towards the problems of small-scale farmers and the rural poor in the hopes of enhancing its poverty-reducing impacts.

Given the complex causes underlying poverty and the diversity of livelihoods found among poor people, the relationship between agricultural research and poverty alleviation is necessarily complex. There are a number of pathways through which improved technologies could potentially benefit the poor (Hazell and Haddad, 2001). Within adopting regions, research could help poor farmers directly through increased own-farm production, providing more food and nutrients for their own consumption and increasing the output of marketed products for greater farm income. Small-scale farmers and landless laborers could gain additional agricultural employment opportunities and higher wages within adopting regions. Research could also empower the poor by increasing their access to decision-making processes, enhancing their capacity for collective action, and reducing their vulnerability to economic shocks via asset accumulation.

Agricultural research could also benefit the poor in less direct ways. Growth in adopting regions could create employment opportunities for migrant workers from other less dynamic regions. It could also stimulate growth in the rural and urban nonfarm economy with benefits for a wide range of rural and urban poor people. Research could lead to lower food prices for all types of poor people. It could also improve their access to foods that are high in nutrients and crucial to their well-being – particularly that of poor women.

However, agricultural research could also work against the poor. Some technologies are more suited to larger farms, and some input-intensive technologies that are in principle scale-neutral may nevertheless favor large farms because of their better access to irrigation water, fertilizers, seeds, and credit. Some technologies (e.g., mechanization and herbicides) could displace labor, leading to lower earnings for agricultural workers. By favoring some regions or farmers over others, technology could harm non-adopting farmers by lowering their product prices even though only the adopting farmers benefit from cost reductions.

Given that many of the rural poor are simultaneously farmers, paid agricultural workers, net buyers of food, and earn nonfarm sources of income, the impacts of technological change on their poverty status could be indeterminate, with households experiencing gains in some dimensions and losses in others. For example, the same household might gain from reduced food prices and from higher nonfarm wage earnings, but lose from lower farm gate prices and agricultural wages. Measuring net benefits to the poor requires a full household income analysis of direct and indirect impacts, as well as consideration of the impacts on poor households that are not engaged in agriculture and/or who live outside adopting regions. Much of the controversy that exists in the literature about how R&D impacts on the poor has arisen because too many studies have taken only a partial view of the problem.

There is a large literature on the impacts of agricultural research on the poor in South Asia but hardly any impact studies exist that quantify the research costs of reducing poverty. Many studies focus on assessing changes in income distribution or poverty in areas where new technologies have been adopted, but only a few attempt to link changes in inequity or poverty to research expenditures. More recently, measures of poverty have also been expanded to include broader and less quantifiable social impacts, such as empowerment and changes in social capital. One consequence is that if we focus only on quantitative studies that evaluate the impact of research investments, this section of the paper would be very short indeed and would not do justice to the large amount of research that has been done on poverty issues or to the large number of studies that shed useful light on how improved technologies can benefit the poor at farm and community levels. Those who invest in agricultural research need to know that relevant work has been undertaken with proven poverty-reduction impacts in the field, even if we do not yet have much quantitative evidence to show which types of research give the best poverty impact per dollar invested.

4.2 Evidence on impacts within adopting regions

The initial experience with the GR in Asia stimulated a huge number of studies on how technological change affects poor farmers and landless workers within adopting regions. A number of village and household studies conducted soon after the release of GR technologies raised concern that large farms were the main beneficiaries of the technology and poor farmers were either unaffected or made worse-off. More recent evidence shows mixed outcomes. Small-scale farmers did lag behind large farmers in adopting GR technologies, yet many of them eventually did so. Many of these small-farm adopters benefited from increased production, greater employment opportunities, and higher wages in the agricultural and nonfarm sectors (Lipton with Longhurst, 1989). In some cases, small-scale farmers and landless laborers actually ended up gaining proportionally more income than larger farmers, resulting in a net improvement in the distribution of village income (e.g., Hazell and Ramasamy, 1991; Maheshwari, 1998; Thapa et al., 1992).

Freebairn (1995) reviewed 307 published studies on the GR and performed a meta-analysis. Nearly all the studies that he reviewed focused on changes in inequality and income distribution rather than on absolute poverty, the latter emerging as a more important issue in the 1990s. Freebairn found that 40% of the studies he reviewed reported that income became more concentrated within adopting regions, 12% reported that it remained unchanged or improved, and 48% offered no conclusion. He also found there were more favorable outcomes in the literature on Asia than elsewhere, and that within the Asian literature, Asian authors gave more favorable conclusions than non-Asian authors. Later studies did not report more favorable outcomes than earlier studies, thereby casting some doubt on the proposition that small-scale farmers adopted, albeit later than large-scale farmers. However, it should be noted that Freebairn's analysis did not include repeat studies undertaken at the same sites over time, such as Hazell and Ramasamy (1991) and Jewitt and Baker (2007), both of whom found favorable longer-term impacts on inequality. Freebairn (1995) also found that micro-based case studies reported the most favorable outcomes, while macro-based essays reported the worst outcomes.

Walker (2000) argued that reducing inequality is not the same thing as reducing poverty, and that it may be much more difficult to achieve through agricultural R&D. More recent studies focusing directly on poverty confirm that improved technologies do impact favorably on many small-scale farmers, but the gains for the smallest farms and landless agricultural workers can be too small to raise them above poverty thresholds (Hossain et al., 2007; Mendola, 2007). However, the poor can benefit in other ways too. Hossain et al. (2007) found that in Bangladesh the spread of high-yielding variety (HYV) rice helped reduce the vulnerability of the poor by stabilizing employment earnings, reducing food prices and their seasonal fluctuations, and enhancing their ability to cope with natural disasters. In India, Bantilan and Padmaja (2008) found that the spread of ICRISAT's groundnut improvement technology based on a RBF concept helped increase social networking and collective action within adopting villages, and this proved especially helpful to poor farmers and women in accessing farm inputs, credit, and farm implements, and in sharing knowledge. Use of participatory research methods in the selection of improved rice varieties in Uttar Pradesh, India has been shown to empower women as decision-makers in their farming and family roles, as well as leading to greater adoption of improved varieties (Paris et al., 2008).

The lessons from many past studies may have less relevance today because of the changing nature of the livelihoods of the rural poor in south Asia. With rapid growth in nonfarm opportunities in much of South Asia as well as shrinking farm sizes, farming and agricultural employment have become less important in the livelihood strategies of the rural poor (Nargis and Hossain, 2006; Kajisa and Palanichamy, 2006; Lanjouw and Shariff, 2004). Within this new context, many poor people with limited access to land gain more from nonfarm opportunities than from productivity gains or wage earnings in farming, though investments in education and access to capital are often crucial for accessing such opportunities (World Bank, 2007; Nargis and Hossain, 2006; Kajisa and Palanichamy, 2006; Krishna, 2005). This is not to say that publicly funded agricultural research cannot still usefully be targeted to the problems of poor part-time farmers. Hazell and Haddad (2001) identified several opportunities, including increasing the productivity of food staples to free up land and labor for other activities, improving the nutrient content of staples, developing new technologies for small-scale home gardening of micronutrient-rich food, and using participatory research methods to enhance the relevance of improved technologies for poor farmers. But questions arise about the efficacy of these kinds of interventions and whether they are cost effective in reducing poverty compared to alternative types of interventions. Answering these questions should be a priority for future impact studies.

4.3 Evidence on economy and sector-wide impacts

There is a large econometric literature that uses cross-country or time-series data to estimate the relationship between agricultural productivity growth and poverty. These studies generally found high poverty reduction elasticities for agricultural productivity growth. Thirtle et al. (2003) estimated that each 1% increase in crop productivity reduces the number of poor people by 0.48% in Asia. For India, Ravallion and Datt (1996) estimated that a 1% increase in agricultural value added per hectare leads to a 0.4% reduction in poverty in the short run and 1.9% in the long run, the latter arising through the indirect effects of lower food prices and higher wages. Fan et al. (2000b) estimated that each 1% increase in agricultural production in India reduces the number of rural poor by 0.24%. For South Asia, these poverty elasticities are still much higher for agriculture than for other sectors of the economy (World Bank, 2007; Hasan and Quibria, 2004).

There is some evidence that the poverty elasticity of agricultural growth may be diminishing because the rural poor are becoming less dependent on agriculture. In Pakistan, for example, agricultural growth was associated with rapid reductions in rural poverty in the 1970s and 1980s, but the incidence of rural poverty hardly changed in the 1990s despite continuing agricultural growth (Dorosh et al., 2003). Dorosh, et al. (2003) show that this is partly because a growing share of the rural poor households (46% by 2001–2002) had become disengaged from agriculture; even small farm households and landless agricultural worker households received about half their income from nonfarm sources.

Some of the studies reviewed in Section 3 that quantified the productivity impacts of public investments in agricultural R&D also assessed the impacts on poverty reduction and provide comparisons with other types of public investment. Fan et al. (1999) found that agricultural R&D investments in India have not only given the highest productivity returns in recent decades, but have also lifted more people out of poverty per unit of expenditure than most other types of public investment (Table 5).

Investments in agricultural R&D and rural roads dominate all others in terms of the size of their impacts, and can be considered the best win–win strategies for achieving growth and poverty alleviation in India.

Fan et al. (2007) have used an econometric model to estimate the impact of rice research in India on poverty reduction, including providing a breakout of an estimate of IRRI's contribution. They found that about 5 million rural poor people have been lifted out of poverty each year as a result of rice improvement research in India. Using plausible attribution rules, they estimated that IRRI's research contribution accounts for significant shares of these annual reductions in the number of rural poor. In 1991, IRRI was attributed with raising 2.73 million rural poor people out of poverty, but because of the lag structures in their model, the contribution declined over time to only 0.56 million rural poor in 1999. They calculated that the number of persons lifted out of poverty for each US$1 million spent by IRRI declined from 59,040 in 1991 to 15,490 persons in 1999. This corresponds to an increase in the cost of raising each person out of poverty from US$0.046 per day in 1991 to US$0.177 per day in 1999.

Fan (2007) also estimated the impact of agricultural research on urban poverty in India. He estimated that in 1970, accumulated agricultural research investments lifted 1.2 million urban poor out of poverty, and this annual reduction increased to 1.7 million by 1995. These numbers correspond to between 2 and 2.5% of the remaining urban poor each year. On a cost basis, 196 urban poor were lifted out of poverty in 1970 for each million rupees spent, and this had declined to 72 urban poor per million rupees by 1995. Since the same investment on research also lifted many rural poor out of poverty (see above), there is a double dividend that makes research investments especially attractive for reducing poverty.

Lower food prices and growth linkages to the nonfarm economy played a large role in most of the results cited above, and these benefit the urban as well as the rural poor. These indirect impacts have sometimes proved more powerful and positive than the direct impacts of R&D on the poor within adopting regions (Hazell and Haddad, 2001). A question arises as to whether the power of these indirect benefits has diminished over time with market liberalization and greater diversification of South Asian economies. Also, if unit production costs are not falling as in the past (as reflected in stagnating TFP growth) this will also constrain future food price reductions. This is an issue that warrants further study.

4.4 Evidence on inter-regional disparities

Agricultural development in South Asia has not benefited all regions equally; some of the poorest regions that depend on rainfed agriculture were slow in benefiting from the GR (Prahladachar, 1983). The widening income gaps that resulted have been buffered to some extent by inter-regional migration. In India, the GR led to the seasonal migration of over a million agricultural workers each year from the eastern states to Punjab and Haryana (Oberai and Singh, 1980; Westley, 1986). These numbers were tempered in later years as the GR technology eventually spilt over into eastern India in conjunction with the spread of tube wells. In a study of the impact of the GR in a sample of Asian villages, David and Otsuka (1994) asked whether regional labor markets were able to spread the benefits between adopting and non-adopting villages and found that seasonal migration did go some way to fulfilling that role. But while migration can buffer widening income differentials between regions, it is rarely sufficient to avoid them. In India, for example, regional inequalities widened during the GR era (Galwani et al., 2007), and the incidence of poverty remains high in many LFAs (Fan and Hazell, 2000).

4.5 Evidence on nutrition impacts

Agricultural research has been very successful in increasing the supply of food and reducing prices of food staples in South Asia. Making food staples more available and less costly has proved an important way through which poor people benefited from technological change in agriculture (Rosegrant and Hazell 2000; Fan et al., 1999; Fan, 2007). Several micro-level studies from the GR era in South Asia found that higher yields typically led to greater calorie and protein intake among rural households within adopting regions. For example, Pinstrup-Andersen and Jaramillo (1991) found that the spread of HYV rice in North Arcot district, South India, led to substantial increases over a 10-year period in the energy and protein consumption of farmers and landless workers. Their analysis showed that, after controlling for changes in nonfarm sources of income and food prices, about one-third of the calorie increase could be attributed to increased rice production. Ryan and Asokan (1977) also found complementary net increases in protein and calorie availability as a result of GR wheat in the six major producing states of India, despite some reduction in the area of pulses grown.

More aggregate analysis of the impacts of rising incomes on diets and nutrient intake has proved more complex, particularly as concern has shifted from calorie and protein deficiencies to micronutrients and broader nutritional well-being. Food price declines are, in general, good for households that purchase more food than they sell, as this amounts to an increase in their real income. Real income increases can be used to increase consumption of important staples and to purchase more diverse and nutritionally rich diets. However, a study of Bangladesh showed that a downward trend in the price of rice between 1973–1975 and 1994–1996 was accompanied by upward trends in the real prices of others foods that are richer in micronutrients, making these less accessible to the poor (Bouis, 2000). Similar patterns were observed in India during the 1970s and 1980s when farmers diverted land away from pulses to wheat and rice, leading to sharp increases in the price of pulses and a drop in their per capita consumption (Kennedy and Bouis, 1993; Kataki, 2002).

Since then, there have been substantial changes in food intake patterns in rural India. In particular, the share of cereals in total food expenditure has declined, while that of milk, meat, vegetables, and fruits has increased. Per capita consumption of cereals has also fallen in absolute terms (Nasurudeen et al., 2006). It is significant that these substitutions occurred both among the rich and the poor; not only do the top 25% spend relatively greater amounts on milk, meat, and other nutrient-rich foods, the decline in the share of staples is also apparent among the poorest 25% (J.V. Meenakshi, personal communication). However, since deficiencies in iron and the B vitamins are common among the poor, the increases in micronutrient-rich foods must not always have been high enough to offset the decline from cereals. Other micronutrient deficiencies exist (e.g., vitamins C and D), but these are not related to reductions in cereal consumption.

Agricultural research has been directed at the problem of enhancing the nutritional quality of the diets of the poor. The main research strategies are:

- Improvements in the productivity of fruits, vegetables, livestock, and fish, both in home gardens and ponds for on-farm consumption and more generally to increase the marketed supplies of these nutrient-rich foods
- Promotion of food-crop biodiversity, especially traditional crops and cultivars that are rich in nutrients
- Biofortification of major food staples.

Ali and Hau's (2001) assessment of AVRDC's program in Bangladesh showed significant improvements in nutrition among participating farm families, as well as increased supplies and lower-priced vegetables in the market. However, they also found that while home gardens can increase incomes as well as improve nutritional intake, they are not sufficient to improve nutrition to desired levels and there is still need for nutritional education. After reviewing 30 agricultural interventions (including six from South Asia) to improve nutrition among participating families, Berti et al. (2004) also conclude that interventions need to be complemented by investments in nutrition education and health services and targeted in ways that empower women with additional spending power.

Biofortification research is relatively new and, although the CGIAR and its national partners are working together on some aspects of this under the aegis of the Harvest Plus Challenge Program (Bouis et al., 2000), it is rather early to measure any impacts, although one *ex ante* study has been completed (Meenakshi et al., 2007).

5. Environmental impacts

5.1 Environmental impact pathways

Agricultural growth can impact on the environment in many ways and it is helpful to distinguish between the problems associated with intensive irrigated and high-potential rainfed areas, where agricultural growth is largely of the land-intensification (yield-increasing) type, and the problems of less-favored or less-developed areas, where agricultural growth is often of the expansionary (land-increasing) type. It should be noted, however, that the problems of the two types can sometimes overlap. The drivers of change and the appropriate research and policy responses are quite different in these two environments (Hazell and Wood, 2008).

In LFAs, crop area expansion is often realized by reductions in the length of fallows and by encroachment into forests and fragile lands (e.g., steep hillsides and watershed protection areas), resulting in land erosion, declining soil fertility, and loss of biodiversity. Expansionary pathways in South Asia are typically associated with areas of poor infrastructure and market access, poverty, and population pressure.

Agricultural intensification in high-potential areas helps avoid the kinds of problems that prevail in many LFAs. By increasing yields, it reduces pressure to expand the cropped area, helping to save forest and other fragile lands from agricultural conversion (Nelson and Maredia, 1999). But intensification often brings its own environmental problems. These include water contamination with nitrates and phosphates from fertilizers and manures, pesticide poisoning of people and wildlife, unsustainable extraction of irrigation water from rivers and groundwater, and loss of biodiversity within agriculture and at landscape levels (Santikarn Kaosa-Ard et al., 2000; Pingali and Rosegrant, 2001). Intensification pathways are associated with the GR and arise mostly in irrigated and high-potential rainfed areas.

Just how serious are the environmental problems associated with agriculture, and are they likely to undermine future production and South Asia's ability to feed itself? Measuring environmental impacts of research and technological change is difficult and as a result good empirical evidence is fragmentary, often subjective, and sometimes in direct contradiction with the overall trends in agricultural productivity. The available evidence tells a mixed story.

Some good news is that despite continued agricultural growth, the total forest area in South Asia has changed little since 1990 (Table 11). Declines in Nepal, Pakistan and Sri Lanka have been offset by forest expan-

Table 11. Change in extent of forest and other wooded land ('000 ha)

	Forest			Other wooded land		
Country	1990	2000	2005	1990	2000	2005
Bangladesh	882	884	871	44	53	58
Bhutan	3035	3141	3195	566	609	611
India	63,939	67,554	67,701	5894	4732	4110
Nepal	4817	3900	3636	1180	1753	1897
Pakistan	2527	2116	1902	1191	1323	1389
Sri Lanka	2350	2082	1933	0	0	0
Total	**77,580**	**79,677**	**79,238**	**8875**	**8470**	**8065**

Source: FAO (2005)

sion in India. There has, however, been a 10% decline in the total area of other woodland, including a 30% reduction in India, which may be a better indicator of the competition between tree cover and agricultural expansion, particularly in LFAs.

Less encouraging are several international land-assessment exercises that have reported widespread degradation of most types of agricultural land in South Asia. The Global Land Assessment of Degradation (GLASOD) mapping exercise of Oldeman et al. (1991) found that 43% of South Asia's agricultural land was degraded to some degree. Young (1993) subsequently revisited these estimates using additional national data, claiming the problem was actually more severe and that nearly three-quarters of the agricultural land area was degraded to some extent, and that 40% was moderately or severely degraded (Table 12). Degradation associated with irrigation accounts for 23% of the total degraded area and for 25% of the moderately or severely degraded area. For India, Sehgal and Abrol (1994) estimated that 64% of the land area is degraded to some extent, with 54% moderately to severely degraded.

Although these data provide a useful warning, they do not tell us much about the causes. Agriculture is only one contributing factor; others include geological processes (especially in the Himalayas), mining, road construction, and urban and industrial encroachment. Even where agriculture is responsible, we need to separate out the land degradation due to agricultural extensification versus agricultural intensification. It is also hard to reconcile some of these estimates with the continuing growth in average yields and land productivity across South Asia. While there are reports of hotspot areas where degradation is adversely affecting both the productivity and sustainability of land, there must be large areas where agricultural productivity is not adversely affected and where the problems are overstated. Some of the problem areas are intensively farmed irrigated areas, but many are rainfed farming areas that, especially in the Himalayas and semi-arid areas, are farmed more extensively.

More detailed data are available about the impact of irrigation on the waterlogging and salinization of irrigated land:

- About 4.2 million hectares of irrigated lands (26% total) are affected by salinization in Pakistan (Ghassemi et al., 1995). Chakravorty (1998) claims that one-third of the irrigated area in Pakistan is subject to waterlogging and 14% is saline. Salinity retards plant growth – he also claims agricultural output is lower than it would otherwise be, by about 25%.
- Dogra (1986) estimates that in India nearly 4.5 million hectares of irrigated

Table 12. Extent of degradation of agricultural land in South Asia[a]

Type of degradation	% total that is degraded	% total that is moderately or severely degraded
Water erosion	25	15
Wind erosion	18	13.9
Soil fertility decline	13	1.3
Waterlogging	2	1.5
Salinization	9	6.5
Lowering of water table	6	2.4
Total	**73**	**40.6**

a. Includes Afghanistan, Bangladesh, Bhutan, India, Iran, Nepal, Pakistan, and Sri Lanka.
Source: Young (1993) as summarized by Scherr (1999)

land are affected by salinization and a further 6 million hectares by waterlogging; India had about 57 million hectares of net irrigated land in the late 1990s. Umali (1993), quoted in Maredia and Pingali (2001, p. 13) claims that 7 million hectares of arable land has been abandoned in India because of excessive salt.
- In a random sample of 110 farmers from four villages in Uttar Pradesh, Joshi and Jha (1991) found a 50% decline in crop yields over 8 years due to salinization and waterlogging in irrigation systems.

Even more disconcerting for irrigated agriculture is the threat from the growing scarcity of fresh water in much of South Asia. Many countries are approaching the point where they can no longer afford to allocate two-thirds or more of their fresh water supplies to agriculture (Comprehensive Assessment Secretariat, 2006). Most of the major river systems in South Asia are already fully exploited, and the massive expansion of tubewell irrigation in Bangladesh, India, and Pakistan has led to serious overdrawing of groundwater and falling water tables.

On the Indian subcontinent, groundwater withdrawals have surged from less than 20 cubic kilometres to more than 250 cubic kilometres per year since the 1950s (Shah et al., 2003). More than a fifth of groundwater aquifers are overexploited in the Punjab, Haryana, Rajasthan, and Tamil Nadu, and groundwater levels are falling (World Bank, 2007; Postel, 1993). Even as current water supplies are stretched, the demands for industry, urban household use, and environmental purposes are growing (Comprehensive Assessment Secretariat, 2006; Rosegrant and Hazell, 2000). It would seem that either farmers must learn to use irrigation water more sparingly and more sustainably, or the irrigated area will have to contract.

Finally, as discussed in Section 3, there is growing evidence from long-term crop trials and declining TFP of the adverse impact of environmental stress on crop yields in some GR areas. This may be the result of the formation of hard pans in the sub-soil, soil toxicity buildups – especially iron – and micronutrient deficiencies – especially zinc (Pingali et al., 1997).

5.2 The R&D response

A growing awareness of these environmental problems has led to significant changes in agricultural R&D in South Asia since the early GR years. It has led to the entry of environmentally oriented NGOs, some of whom have contested the GR approach and undertaken research and extension activities of their own to broaden the spectrum of technologies and farming practices available to farmers. The national and international R&D systems have also invested heavily in NRM research and technologies and management practices for improving water, pest, and soil fertility management.

One of the outcomes of greater NGO involvement has been a lively debate about competing farming paradigms, and 'alternative' farming[8] has been offered as a more sustainable and environmentally friendly alternative to the modern-input based approach associated with the GR. The alternative farming approach includes extremes that eschew use of any modern inputs as a matter of principle (e.g., organic farming), but also includes more eclectic whole-farming systems approaches such as low external input farming (Tripp, 2006) and ecoagriculture (McNeely and Scherr, 2003). Pretty (2008) provides a useful review of these approaches.

While the alternative farming literature provides many successful examples of agricultural intensification, most of these have arisen in rainfed farming systems that largely missed out on the GR. We shall review several of these experiences in Section 5.4 on LFAs. But by 'sleight of aggregation', proponents of alternative agriculture frequently mix these kinds of successes with much more modest results obtained in GR areas, giving the impression that productivity levels can be increased significantly across the board by switching to alternative farming approaches. In fact, most alternative farming approaches cannot match the high productivity levels achieved by modern farming methods in GR areas. Pretty et al. (2007) in a revisit of Pretty et al. (2003) examined yield claims for 286 sustainable agriculture projects

8 Sometimes also called 'sustainable' or 'ecological' farming.

disaggregated into eight farming systems categories developed by Dixon et al. (2001) and showed that the more sizeable gains nearly all arose within rainfed farming systems. Moreover, the gains reported for rice and wheat yields, the main GR crops, were modest, sometimes even negative.

Despite significant R&D investments in environmentally oriented research of both paradigms, there are very few impact studies of the value of that work. As with poverty impact assessment, the state of the art in assessing environmental impacts in ways that can be quantified in social cost–benefit calculations is still poorly developed. This is partly because of difficulties in measuring environmental changes over the time spans and levels of scale required, and also because of difficulties in assigning economic values to changes, even when they can be measured (Freeman et al., 2005). The few impact studies that exist either report changes in selected physical indicators or rely on farmers' perceptions of change in resource or environmental condition. However, these are sufficient to demonstrate that relevant work has been undertaken with proven productivity and environmental impacts in the field, even though we do not yet have calculations of the rates of return to those investments to show which types of institutions or research give the best returns.

In reviewing these developments and their impacts, we continue with the useful distinction between intensively farmed GR areas and extensively farmed LFAs.

5.3 Evidence on impact in Green Revolution areas

Only a few GR critics argue for a drastic reversal from GR to traditional technologies of the kinds that dominated South Asia before the GR (e.g., Shiva, 1991; Nellithanam et al., 1998). Such authors claim that yield growth rates were already high before the GR, but ignore the fact that this was largely the result of the spread of irrigation and fertilizers prior to the introduction of HYVs (Evenson et al., 1999). More generally, R&D has contributed to a broad range of technologies for improving soil, water and pest management in GR areas that span the spectrum from zero use of modern inputs to high but precision-managed use.

Organic farming

Despite widespread publicity to the contrary, organic farming seems to have little to offer farmers in GR areas who wish to continue to grow cereals. A recent study (Halberg et al., 2006, p. 40) concludes: "In high-yielding regions with near to economic optimal inputs of fertilizers and pesticides, the yields of organic farming are between 15 and 35% lower than present yields when comparing single crops, and possibly at the low end (35%) when including crop failures and the need for green manure in crop rotations."[9] This statement draws heavily on results from temperate countries, and crop losses could be even higher in tropical countries because of greater problems with pest and disease control. The same study concludes that organic farming has more to offer farmers in less-intensively farmed areas, such as many LFAs, or farmers who can benefit from price premiums for organically produced foods. Zundel and Kilcher (2007) report somewhat lower yield losses for organic farming in temperate and irrigated areas, but do not allow for crop failures and diversion of land to produce green manure and other organic matter.

Badgley et al. (2007) reviewed a large number of published studies comparing organic and conventional crops. Although they claim organically grown grains in developing countries have an average yield advantage of 57%, the more detailed results in their Table A1 tell a more nuanced story. Organically grown rice under irrigated conditions in South Asian countries showed little if any yield gain. The best organic farming yield gains for South Asia were obtained on upland rice and for maize and sorghum grown under

9 Since organic agriculture involves greater generation of plant nutrients and organic matter within the landscape through crop rotations, fallows, green manures, and integration of livestock into cropping systems, each hectare of cropland harvested must be supported by additional land dedicated to these other needs. While it might well be possible to obtain comparable yields for some crops at the plot level, farm level productivity can be considerably lower for organic farming. Yet few studies of yield gains with organic farming seem to make this basic correction, leading to results that are inevitably biased in their favour.

rainfed conditions. These are areas where the conventionally grown crops usually receive limited nutrient inputs of any kind and hence produce low yields.

System of rice intensification (SRI)

SRI was developed in the early1980s by Henri de Laulanie, a French missionary priest in Madagascar, as another alternative farming approach to the available GR rice technologies for small-scale farmers. It has since been widely promoted by a number of NGOs and the International Institute for Food, Agriculture and Development (IIFAD) at Cornell University (http://ciifad.cornell.edu/sri). Not only was SRI initially developed outside the international and public-sector research systems, but if its claimed benefits proved true, it would render irrelevant much of the research on intensive rice farming that has been conducted in recent decades by the public and international R&D systems. Not surprisingly, SRI has attracted the attention of the scientific and donor communities and sparked a lively debate and research agenda.

The main components of SRI are: transplanting of young seedlings (8–15 day-old instead of 3–4 week-old plants) on small hills at much lower plant densities than usual; water management that keeps the soil moist rather than flooded; frequent weeding; and use of large amounts of organic compost for fertilizer.

The claimed benefits include: high yields even with traditional rice varieties; a significant savings in seed; little or no artificial fertilizer required; natural pest and disease control, eliminating the need for pesticides; reduced water use; and a flexible management that allows farmers to experiment and adapt the approach to their particular growing conditions. The approach is claimed to be environmentally sustainable and of particularly relevance for poorer farmers who cannot afford modern inputs (Uphoff, 2003).

Controversy has arisen because of claims of very high yields, sometimes exceeding the best experiment station yields for modern rice technologies, sometimes even without the use of fertilizer or modern varieties. These high yields defy current understanding of the physiology of rice plant growth (Sheehy et al., 2005). Proponents argue that there are strong synergies between the different management components of SRI that lead to strong root growth and higher yields, although these synergies are not well understood (Mishra et al., 2006).

Few of the yield claims have been verified under controlled experimental conditions. Trials undertaken at IRRI found no significant yield differences between SRI and conventional GR practices (quoted in Namara et al., 2003). McDonald et al. (2006) analyzed 40 sets of field trial results reported in the literature (five from Madagascar and 35 from 11 Asian countries) which compared SRI with 'best management practices' appropriate to each site. Apart from the five Madagascar studies, which consistently showed higher yields with SRI, SRI led to an average yield loss of 11% in the other 35 studies, with a range of -61% to 22%.

Yield gains appear to be better in farm adoption studies. Farmers in Ratnapura and Kurunegala Districts in Sri Lanka obtained 44% higher yields on average with SRI than with modern rice farming methods (Namara et al., 2003), and the average yield gain was 32% for farmers in Purila District of West Bengal (Sinha and Talati, 2007). However, in both studies SRI farmers showed considerable variation in the management methods they used, making it rather unclear as to what was being compared in the name of SRI. For example, many SRI farmers used inorganic fertilizer as well as compost, many grew modern as well as traditional rice varieties, and their weeding and water management practices varied considerably.

SRI has yet to be widely adopted in any one country, although it can be found on small scales in many countries, including many parts of South Asia.[10] Some of the reasons for poor uptake include: the difficulties of controlling water with sufficient precision in many surface irrigation systems, the need for large amounts of compost, and the high labor demands for transplanting, hand weeding[11] and generating and distributing

10 See http://ciifad.cornell.edu/sri

11 The combination of wide spacing and reduced flooding creates ideal conditions for weed growth and hence the need for frequent weeding.

compost. This is confirmed by available adoption studies. In Sri Lanka, adoption is positively related to family size (availability of labor) and ownership of animals (availability of manure) and is more common among rainfed than irrigated rice farmers (Namara et al., 2003). Moser and Barrett (2003) obtained similar results in an adoption study in Madagascar. Moser and Barrett (2003), Namara et al. (2003), and Sinha and Talati (2007) all found that adopters only practice SRI on small parts of their rice area despite higher returns to both land and labor, and they also found high rates of disadoption. This again suggests important constraints, possibly labor or suitability of available irrigation systems, as well as disappointing returns.

Improved nutrient management

More pragmatic approaches to intensive farming seek to increase the efficiency of fertilizer use rather than displace it, thereby reducing production costs and environmental problems. Fertilizer efficiency can be improved through more precise matching of nutrients to plant needs during the growing season, and by switching to improved fertilizers such as controlled-release fertilizers and deep-placement technologies.

Site-specific nutrient management (SSNM) was developed by IRRI and its partners as a way of reducing fertilizer use, raising yields, and avoiding nitrate runoff and greenhouse gas emissions (especially nitrous oxide) from intensive rice paddies (Pampolino et al., 2007). Developed in the mid-1990s, SSNM is a form of precision farming that aims to apply nutrients at optimal rates and times – taking account of other sources of nutrients in the field and the stage of plant growth – to achieve high rice yields and high efficiency of nutrient use by the crop. Farmers apply nitrogen several times over the growing period and use leaf color charts to determine how much nitrogen to apply at different stages. SSNM has been tested through on-farm trials in several Asian countries and IRRI has developed practical manuals and a web site (www.irri.org/irrc/ssnm) to guide application.

Pampolino et al. (2007) provide an economic assessment of SSNM compared to farmers' usual fertilizer practices. They undertook focus group discussions with adopting and nonadopting farmers at sites in India and two sites in Southeast Asia. For India, yields of adopting farmers were found to be 17% higher. Modest savings in fertilizer use were largely offset by higher labor costs, but profit per hectare was 48% higher. There was also a useful reduction in emissions of nitrous oxide, a powerful greenhouse gas. In an impact study in West Bengal, India, Islam et al. (2007) found small (but not significant) increases in yields, but 20% savings in nitrogen use and 50% savings in pesticide use, and economic benefits of US$19–27 per hectare depending on the season.

The International Center for Soil Fertility and Agricultural Development (IFDC) has been pioneering urea deep placement (UDP) technology in rice. This involves the deep placement of urea in the form of supergranules or small briquettes into puddled soil shortly after transplanting the rice (Bowen et al., 2005). The method improves nitrogen-use efficiency by keeping most of the urea nitrogen in the soil close to the plant roots and out of the floodwater where it is susceptible to loss. On-farm trials in Bangladesh that compared UDP with standard urea broadcasting practices showed 50–60% savings in urea use and yield increases of about one ton per hectare (Bowen et al., 2005). The briquettes are also simple to make with small pressing machines, and can create additional local employment. Adoption data are not available, but the approach appears to be spreading in Bangladesh with the active support of the government.

Low or zero tillage (ZT)

In response to the declining growth in productivity of the rice–wheat farming system in the IGP, ZT has been adapted and introduced by the RWC, a partnership of CGIAR centers and the NARS from Bangladesh, India, Nepal, and Pakistan. The technology involves the direct planting of wheat after rice without any land preparation. Rice crop residues from the previous season are left on the ground as mulch. The wheat seed is typically inserted together with small amounts of fertilizer into slits made with a special tractor-drawn seed drill. The technology has many claimed advantages over conventional tillage in the rice–wheat system: it saves labor, fertilizer and energy; minimizes planting delays between crops; conserves soil; reduces irrigation water needs; increases tolerance to drought; and reduces greenhouse gas emissions (Erenstein et al., 2007; World Bank, 2007). But it often requires some use of herbicides for general weed control. A key ingredient for its success has been the development of an appropriate seed drill for local conditions in the IGP.

In an assessment of the technology based on a sample of farmers in Haryana, India and the Punjab, Pakistan, Erenstein et al. (2007) found that ZT adoption has been rapid. In Haryana, 34.5% of the sampled farmers had adopted in 2003/04 and 19.4% in the Punjab, even though diffusion of the technology only began around 2000. Adopting farmers used the technology on large shares of their total wheat areas. Adoption has been highest on larger farms with tractors. The study found mixed results for yield gains and water savings (more significant in Haryana than the Punjab) but all farms made drastic savings in tractor and fuel costs. There were no observed impacts on the following rice crop. Although the technology is attractive to farmers, the high percentage of non-adopting farmers together with disadoption rates of 10–15% suggests continuing constraints on its use. No one factor was clearly identified in the study, but access to tractors and ZT seed drills is important, especially for smaller farms. Rental markets for these machines exist but may not offer farmers sufficient flexibility in the timing of their operations, which is crucial if higher yields are to be obtained. Other ZT assessments from adoption studies, on-farm trials and focus group discussions confirm the large savings in tractor and fuel costs, and most show significant water savings and yield gains (Laxmi et al., 2007; Laxmi and Mishra, 2007).

It is estimated that about 200,000 hectares of wheat was planted under ZT in the Pakistan IGP in 2001/02 and 820,000 hectares in the Indian IGP in 2003/04 (about 8% of the total wheat area). The latter had doubled by 2004/05 (Laxmi et al., 2007). Based on an estimated ceiling adoption rate of 33%, Laxmi et al. (2007) undertook an economic assessment of the likely returns to the research costs incurred by the RWC partners in developing the technology for India's IGP. Even with conservative assumptions about yield gains (6%) and cost savings (5%), the estimated benefit–cost ratio is 39 and the internal rate of return is 57%. With more optimistic assumptions (yield gains and cost savings of 10%), the benefit–cost ratio increases to 68 and the internal rate of return to 66%. This analysis does not include any environmental benefits.

Improved water management

Improved water management in South Asian agriculture is essential for redressing growing water scarcities, improving water quality, and halting the degradation of additional irrigated land. This will require significant and complementary changes in policies, institutions, and water management technologies. Agricultural research has been conducted on all three aspects, although little of this research has been subjected to impact analyses.

Technical research has shown the potential to increase yields in irrigated farming with substantial savings in water use (e.g., Mondal et al., 1993; Guerra et al., 1998). Realizing these gains is easiest when farmers have direct control over their water supplies, as with tubewell irrigation or small-scale farmer-managed irrigation schemes. For larger schemes, the best hope lies in the devolution of water management to local water user groups or associations, an approach known as irrigation management transfer (IMT).

IMT began to be adopted in some South Asian countries during the late 1980s as a response to the disappointing performance of many large-scale irrigation schemes. It was hoped that IMT would increase the accountability of water irrigation services to farmers, encourage greater farmer input into the maintenance of irrigation systems, improve cost recovery, and enable improved control of water at local levels. All this was expected to lead to higher water use efficiency, increased agricultural productivity, better environmental outcomes, and irrigation schemes that were more financially sustainable.

Despite the promise, there was little hard evidence to show that IMT did in fact lead to these realized benefits. IWMI therefore embarked on a set of studies in 1992 to monitor and evaluate the experience with IMT and provide guidelines for its successful implementation in the future. The results from the Asian case studies proved disappointing. Sri Lanka, which began to implement IMT in 1988, is typical of the results obtained. Samad and Vermillion (1999) surveyed irrigation schemes that had been transferred and some that had not, and within each there were schemes that were rehabilitated and some that were not. The findings suggest only modest gains to farmers or the sustainability of irrigation schemes. Farmers in IMT areas did not incur additional water supply costs, but neither did they perceive any improvements in the quality of water services they received from their irrigation agency. There were significant gains in yields, land, and water productivity in some IMT areas, but the best results were obtained in schemes that were both rehabilitated and transferred to producer organizations. Simply devolving management without also rehabilitating the irrigation schemes achieved little.

Following these mixed findings, IWMI embarked on a follow-up program of research to identify best practice approaches from around the developing world. Within South Asia, IWMI subsequently provided policy advice to the governments of Sri Lanka and Nepal in developing national IMT strategies, and engaged in action research in Pakistan and Sri Lanka to help improve implementation policies. This led to the development with the Food and Agriculture Organization of the United Nations (FAO) of a handbook on best practice (Vermillion and Sagardoy, 1999) and to a number of guidelines papers on specific implementation issues.

A subsequent assessment of IWMI's work on IMT is provided by Giordano et al. (2007). They claim significant impact on water policies in Nepal and Sri Lanka and some success in affecting the employment of improved techniques in Pakistan and Nepal. They also report high demand for IWMI's guideline publications on IMT.

Integrated pest management (IPM)

Pest problems emerged as an important problem during the early GR era because many of the first HYVs released had poor resistance to some important pests. The problem was compounded by a shift to higher cropping intensities, monocropping, high fertilizer use (which creates dense, lush canopies in which pests can thrive), and the planting of large adjacent areas to similar varieties with a common susceptibility. Control was initially based on prophylactic chemical applications, driven by the calendar rather than incidence of pest attack. This approach disrupted the natural pest–predator balance and led to a resurgence of pest populations that required even more pesticide applications to control. Problems were compounded by the buildup of pest resistance to the most commonly used pesticides. As pesticide use increased, so did environmental and health problems. Rola and Pingali (1993) found that the health costs of pesticide use in rice reached the point where they more than offset the economic benefits from pest control.

As these problems began to emerge, researchers gave greater attention to the development of crop varieties that have good resistance to important pests and biological and ecological pest control methods. This led to the development of IPM, an approach that integrates pest-resistant varieties, natural control mechanisms, and the judicious use of some pesticides. The CGIAR centers have been important sources of research on IPM, and IRRI has been especially important for IPM in rice in Asia (Waibel, 1999).

Bangladesh has been in the forefront of IPM since 1981, and the government, with assistance from FAO, has aggressively promoted the approach through farmers' training schools. Sabur and Molla (2001) undertook a farm survey in 1997/98 and found that IPM farmers used less than half the amount of pesticides on rice than non-IPM farmers and had significantly higher gross income per hectare. Similar results were obtained by Susmita et al. (2007) and by Rasul and Thapa (2003). Both studies found that IPM farmers saved significantly on costs (labor and pesticides). None of the studies report any significant productivity impact from use or IPM, so the main economic benefits arise from lower costs. Farmers perceived fewer health problems with IPM in all three studies, though neither Susmita et al. (2007) or Rasul and Thapa (2003) could find statistical differences between the perceptions of adopting and non-adopting farmers. None of the studies provides any data on environmental impacts.

There is no hard evidence to show that IPM has been widely adopted among South Asian farmers. There are two difficult constraints to overcome. One is farmer training; IPM is knowledge-intensive, requiring farmers have the capability to identify harmful and beneficial insects and the ability to flexibly manage their response to pest attacks. Farmer field schools have had some success in providing the required training (Waibel, 1999; Tripp et al., 2006; van den Berg and Jiggins, 2007). But this can be a slow and expensive way of training large numbers of farmers – particularly if, as Tripp et al. (2006) found in Sri Lanka, knowledge-intensive methods like IPM do not easily spread from farmer to farmer. The other constraint is the need for collective action among neighboring farmers. IPM cannot be successfully undertaken at single plot or farm levels but must be adopted at landscape levels. This is difficult to organize without effective community or producer organizations.

5.4 Evidence on impact in less-favored areas

Following Pender and Hazell (2000), LFAs are broadly defined in this paper to include lands that have been neglected by humans as well as by nature. They include marginal lands that are of low agricultural potential due to low and uncertain rainfall, poor soils, steep slopes, or other biophysical constraints; as well as areas that may have higher development potential but that are presently under-exploited due to poor infrastructure and market access, low population density, or other socioeconomic constraints. Conceptually they include all the shaded areas in Table 13.

An attempt to operationalize this two-dimensioned concept of LFAs suggests that about one quarter of South Asia's rural population live in LFAs (World Bank, 2007).

Much of the deforestation, woodland loss, and land degradation (including soil erosion and soil fertility loss) that has occurred in South Asia arose in LFAs that did not benefit much from the GR. This degradation is often driven by insufficient agricultural intensification relative to population growth. As more and more people seek to eke a living out of these areas, they expand cropping in unsustainable and erosive ways and fail to replenish the soil nutrients that they remove. While migration and nonfarm development have important roles to play in reducing pressures on the natural resource base, more sustainable forms of agricultural growth are needed if the environmental problems in these areas are to be reversed.

LFAs also account for a significant proportion of the rural poor in South Asia. Precise estimation is difficult because poverty data are reported by administrative units rather than by agroecological areas or farming systems. Fan and Hazell (2000) estimated that 41% of India's rural poor (76 million people) lived in LFAs in 1993, and ICRISAT estimates that 40% of India's rural poor live

Table 13. Classification of favored and less-favored areas

Access to markets and infrastructure	Agricultural potential: High	Agricultural potential: Low (biophysical constraints)
High	Favored areas	Marginal areas (LFAs)
Low	Remote areas (LFAs)	Marginal and remote LFAs

Source: Pender and Hazell (2000)

in the semi-arid tropics and another 16% in arid areas and semi-arid temperate areas (Rao et al., 2005). There is some controversy about whether the incidence of poverty is higher among LFA populations than in irrigated and high-potential rainfed areas, but since estimates range from "no significant difference" (Kelley and Rao, 1995) to "higher concentrations of poor in LFAs" (Fan and Hazell, 2000), this controversy need not detract from the importance of agricultural research for LFAs.

An early and appropriate (at that time) bias during the GR era towards R&D spending on irrigated areas and best rainfed areas has changed. Pal and Byerlee (2006) found no evidence of any underinvestment (relative to irrigated areas) in rainfed and marginal lands by 1996–1998. At a commodity level, Byerlee and Morris (1993) did not find any bias for wheat research, but Pandey and Pal (2007) found a modest bias against LFAs in the allocation of research scientists for rice research. These studies calculate desired research shares on the basis of congruency with agricultural or commodity outputs and not on the basis of poverty. An analysis based on poverty might tell a different story, but that would first require resolving the controversy about where the poor are most concentrated, as well as an analysis of the relative merits of the indirect (e.g., food and labor market) benefits from investing in each type of area (Renkow, 2000). An environmental perspective might also justify greater investment in agricultural research in many LFAs[12].

Most LFAs in South Asia are unsuitable for the kinds of intensive monocrop farming associated with the GR. A lack of irrigation potential, erratic and often deficient rainfall, poor soils, and, often, sloped land make crops less responsive to fertilizers, and the fragility of the resource base requires more integrated and mixed farming approaches to avoid degradation. Economically, the remoteness of many LFAs from markets also makes modern inputs expensive relative to the prices farmers receive for their products. In this context, a lot of research has been targeted at improving NRM practices that conserve and efficiently use scarce water, control erosion, and restore soil fertility while using low amounts of external inputs. These kinds of technology improvements can lead to significant gains in productivity and stability while reversing some types of resource degradation. Within this context, there has been considerable convergence between the objectives and approaches of different farming paradigms for LFAs.

The analysis by Pretty et al. (2007) of yield claims for 286 sustainable agriculture projects from around the developing world showed that the more sizeable gains nearly all arose within rainfed farming systems. Some of the most successful projects for these areas included improved crop varieties, water harvesting, soil, and water conservation at catchment or watershed levels, and use of organic residues for soil improvement. For South Asia, yield gains of 63% are reported for highland mixed farming systems in India, Nepal, Pakistan, and Sri Lanka, and 79% for rainfed mixed farming systems in India.

Of 293 yield ratios for organic versus modern crop production methods, reviewed by Badgley et al. (2007), only 10 have relevance to LFAs in South Asia. There are five ratios for upland rice (ranging from 1.23 in Pakistan to 3.4 in Nepal) and five for sorghum and millets in India (ranging from 1.65 to 3.5). Organic farming in these locations requires mixed farming, soil and water conservation, and use of organic residues for soil improvement.

While there are grounds to be skeptical about the high yield levels claimed in some of these studies (Cassman, 2007), they are consistent with the fact that the existing farming systems are low-yielding, usually because of low rates of application of fertilizers or organic matter and poor soil and water management. In these circumstances, many improved NRM practices that reverse land degradation, improve soil condition, and provide much-needed water and nutrients for crops can make a large difference, whether motivated by alternative or modern agricultural philosophies. Even so, one recent study undertaken in a less-developed and hilly area of Himachal Pradesh, India, found that while organically grown wheat

12 An attempt to prioritize agricultural R&D on the basis of production, poverty, and environmental goals has been undertaken by Mruthyunjaya et al. (2003).

and maize were more profitable than their modern production counterparts, this was nearly all due to a price premium of about 100% (Thakur and Sharma, 2005).

Important lines of research in LFAs involving CGIAR centers in South Asia include crop improvement, watershed development, and integrated soil nutrient management.

Crop improvement research

Much plant breeding for LFAs has focused on producing varieties that can withstand drought and poor soil conditions and that have greater pest and disease resistance. Such varieties can raise average yield response and reduce yield instability. They can also contribute to reductions in pesticide use and, by raising the productivity of food crops, help reduce the cropped area needed by subsistence-oriented farmers. This can reduce the pressure on more fragile lands and free up some land and labor for other activities. Most of ICRISAT's crop improvement research is directed at LFAs, and there are spill-in benefits to these areas from the crop improvement work that IRRI (upland rice), CIMMYT (maize), and CIP (potatoes) undertake more broadly in Asia.

At an aggregate level, there is evidence from India that crop improvement research is having favorable productivity and poverty impacts in many LFAs (Fan and Hazell, 2000). Based on an econometric analysis of time-series data for three different types of agricultural areas (irrigated, high-potential rainfed, and low-potential rainfed), they found more favorable marginal returns (measured as rupees of agricultural production per additional hectare planted to modern varieties) for crop improvement research in low-potential rainfed areas than in either high-potential rainfed areas or irrigated areas. Moreover, additional crop research investment in low-potential rainfed areas lifts more people out of poverty than in the other two types of areas. Fan et al. (2000a) provide a more nuanced set of results for 13 different types of rainfed zones in India. They found seven zones where the benefit–cost ratio for additional crop-improvement research is greater than five and where there are also favorable poverty impacts. Neither of these studies assesses environmental impacts.

The measured impacts of some of the commodity-improvement work reviewed in Section 3.2 have arisen in LFAs (e.g., maize, sorghum, and millet), although the cited studies do not separate out the impacts in LFAs from GR areas. However, a few examples illustrate the impacts of crop-improvement research that was targeted to the specific problems of poor people in LFAs.

As mentioned earlier, Shiyani et al. (2002) found that ICRISAT-improved chickpea varieties have been widely adopted in a poor tribal area in Gujarat, India, with favorable impacts on yields, unit production costs, and net returns per hectare.

ICRISAT's package of improved groundnut varieties grown in combination with improved agronomy practices built around an RBF concept (see Table 9 and earlier discussion) is another example of a commodity-improvement program that has paid off handsomely in an LFA – in this case the semi-arid tropical areas of central India. The high internal rate of return of about 25% reported by Joshi and Bantilan (1998) is seemingly robust to within a percentage point or two, even when corrected for possible positive and negative environmental outcomes that affect yield and production costs (Bantilan et al., 2005). This is one of the few available impact studies that attempts to value environmental impacts within a benefit–cost analysis framework.

Watershed development

There have been significant investments in research on watershed development in South Asia in recent decades. India began developing model operational research projects in a number of representative watersheds in the mid-1970s, and these were used to test and validate integrated watershed management approaches before they were scaled up in huge publicly funded schemes across the country. By 1999/2000, India had spent Rs. 35,915 million to develop 37 million ha, or 22% of the problem area (Babu and Dhyani, 2005), and by the late 1990s was spending about US$500 million each year on additional watershed development projects (Kerr et al., 2000). The total had exceeded US$2 billion by 1999/2000 (Joshi et al., 2004). ICRISAT and IWMI have both undertaken research on watershed development and related soil and water management issues and have been involved in watershed evaluation work.

There have been many evaluations of watershed development projects in India, though seemingly none on the returns to research on watershed development. Joshi et al. (2005b) undertook a meta-analysis of 311 evaluation studies spanning a large number of types of projects and agroclimatic conditions. They found that the average benefit–cost ratio was 2.14 (with a range of 0.8–7.1), and the average internal rate of return was 22% (with a range of 1.4–94%). On average, the projects created additional employment of 181 days per hectare per year, increased the irrigated area by 34% and the cropping intensity by 64%, and slowed soil losses by 0.82 tons per hectare per year. Among other things, the meta-analysis showed that the benefit–cost ratio was:

- Higher in areas with annual rainfall of between 700 and 1100 mm than in areas with low (less than 700 mm) or high (greater than 1100 mm) rainfall
- 42% greater in macro-watersheds (greater than 1250 hectares) than in micro-watersheds
- Larger when state governments were involved in the planning and execution compared to purely central government projects
- Higher when there was active people's participation.

Kerr et al. (2000) surveyed 86 villages in Maharashtra and Andhra Pradesh, some of which were included in watershed projects and some not. Three types of projects were included: government (Ministry of Agriculture)-run projects, NGO-run projects, and projects that were run collaboratively between NGOs and state government. The government projects largely focused on technical improvements; NGO projects focused more on social organization; and the collaborative projects tried to draw on the strengths of both approaches. Qualitative and quantitative data were both collected, including data on conditions in the study villages before and after the projects were implemented.

Overall, the participatory NGO projects performed better than their technocratic, government-run counterparts. However, participation combined with sound technical input performed best of all. For example, while all projects reduced soil erosion on uncultivated lands in their upper watersheds reasonably well, the NGO and NGO/government collaborative projects had particularly good records in this regard. Greater NGO and community involvement also helped ensure that project investments were maintained over time. Although definitive hydrological data were not available, farmers in villages in NGO and NGO/government projects frequently perceived that the projects' water-harvesting efforts increased the availability of water for irrigation and their net returns to rainfed farming were higher.

6. Policy impacts

The economic transformation of South Asia in recent years and the huge success of the GR have necessitated some major changes in agricultural policies. With market liberalization, the established roles 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.

A vast policy research literature written during this period in South Asia is testament to the prolific response of the region's own researchers. The CGIAR centers have also been active participants, including through networking endeavors, such as that created by IFPRI in the Policy Analysis and Advisory Network for South Asia (PAANSA), described in an evaluative manner by Paarlberg (2005; http://www.ifpri.org/impact/ia24.pdf). ICRISAT, IRRI, and IWMI, for example, have contributed many policy studies for improving adoption of improved technologies, NRM, and IPM (Pingali et al., 1997; Pingali and Rosegrant, 2001). IWMI has contributed to improved understanding of water policies from river basin management to management of irrigation schemes to water management in farmers' fields. ICRISAT has worked on policy issues related to mechanization, risk and technology design, herbicides and equity, marketing, credit policies, and watershed management. IFPRI has contributed to many of these issues and to a wide range of other policy issues, including market and trade policy reform, public investment, food subsidies, and environmental issues. Other external agencies such as the World Bank and Asian Development Bank have also made many important analytical contributions.

It is difficult to tease out the impact of all this policy research, and even more so to try to attribute any impact to the CGIAR centers. Many of the policy reforms are not yet complete (e.g., the phasing out of key input subsidies and reform of water policies), and some might have been implemented regardless without the benefit of policy research. Fortunately, a few impact assessments have been undertaken that shed some light on the value of policy research in South Asia in recent years.

Water policy

IWMI's work on IMT has already been reviewed in Section 5.3. Giordano et al. (2007) show that this work led to significant impact on water policies in Sri Lanka and had some success in affecting the employment of improved techniques in Pakistan and Nepal. They also report high demand for IWMI's guideline publications on IMT.

Bangladesh: Changing the course of food and agricultural policy

During 1989–1994, IFPRI placed a small team of researchers in Bangladesh to collaborate with the Ministry of Food on a set of research activities to guide aspects of the market liberalization program. The impact of this program is reviewed by Babu (2000). A study of the comparative advantages of different crops guided the development of a new strategy aimed at diversifying agriculture. Studies of rice and wheat markets found that the government could turn grain procurement and sales over to the private sector without harming the food security of the poor. When the government opened the grain markets to private-sector participation, it saved US$37 million by lowering the official procurement price.

An IFPRI study of the rural food ration program uncovered poor management and substantial leakages. The government had long been aware that the ration program was not effectively reaching its intended beneficiaries – the rural poor – and the study put hard numbers to the government's suspicions. By eliminating the program, the government saved US$60 million. Some of these savings were used to increase expenditures on other better targeted food and nutrition programs, including the innovative 'Food for Education' program. Later evaluations found that this program raised school attendance by about 30%. Besides these policy changes, the research resulted in other more effective programs and strategies and saved the government at least US$100 million, many times the research cost of less than US$5 million (Babu 2000; Ryan and Meng, 2004). Moreover, the collaboration increased the body of knowledge on food policy in Bangladesh and the number of people equipped to make use of it, by producing more than 70 research reports and providing training in food policy analysis to over 200 individuals.

Pakistan: Examining the effectiveness of subsidies

In collaboration with the Pakistan Institute of Development Economics (PIDE) and the Pakistan Ministry of Food and Agriculture, IFPRI's research and policy dialogue were instrumental in changing the direction of food and agricultural policies in Pakistan. The impact of the program is reviewed by Islam and Garrett (1997). From 1986 to 1994, this collaboration produced a large body of research – over 80 journal articles and research manuscripts – that policymakers drew on as they made policy decisions. IFPRI's research, from 1986 to 1991, resulted in over US$200 million in savings to the government. The total cost of research for the entire period was only about US$6 million.

IFPRI's work on the wheat ration shop program provides a clear example of the changes Pakistan made in its food policies. In this program, poor consumers were able to buy subsidized wheat from special shops. By the 1980s, the government was spending millions on a program that was, by most accounts, corrupt and ineffective. Policymakers wanted to know if the program helped the poor or not, and what the effects on the poor would be if the program were eliminated. In a national survey, IFPRI-PIDE research showed that well over half the wheat never reached the target population. Only 19% of the population in cities and 5% of the population in rural areas, where most of the poor lived, even used the ration shops. The research put numbers to the program's failure to reach the poor, a finding that was expected but until then had been based mostly on conjecture, anecdotes, and one small study. The research provided solid data to drive the final nail in the coffin of the ration shop system. The government abolished the wheat ration shops in 1987.

7. Conclusions

The post-GR period has seen profound changes in the economic situation in South Asia and evolving challenges for the agricultural R&D system. The priorities have changed from a narrow focus on the productivity of foodgrains to a need for more work on NRM and sustainability issues; 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 both national and international systems have responded well to these changing needs 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 NGOs have helped ensure that important research and extension needs have not been overlooked.

There is also reasonable evidence to show that agricultural R&D has been broadly successful in achieving many of its new goals.

Productivity impacts

The economic returns to crop improvement research have remained high and well in excess of national discount rates. Public investments in crop improvement research have also given 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.

Given the patchy nature of the available impact studies and the fact that few have attempted to make any direct attribution to the work of the CGIAR centers, only a few inferences can be offered about the returns to CGIAR investments. One approach is to attribute to CGIAR investments the same rates of return as those achieved at national levels for aggregate measures of public research expenditure. This would suggest an annual rate of return of between 25–50% (Table 4). Assuming a sustained annual investment of around US$65 million (see Section 2.3), this leads to an annual average payoff of between US$17.5 million and US$35 million. But this estimate is much lower than the payoffs suggested for recent years by Fan (2007), Lantican et al. (2005), and Morris et al. (2003). As discussed in Section 3.3, these studies suggest annual payoffs from the CGIAR's research of between US$432 million and US$2304 million for rice, US$560 million to US$1710 million for wheat, and US$45 to US$62 million for maize research. Even without including the CGIAR's other lines of research, the estimated payoff already exceeds US$1 billion each year, which is more than enough to cover the costs of the CGIAR's entire global program, let alone the US$65 million or so spent in South Asia each year. These kinds of calculations are at best indicative, but they do suggest that, from a narrow productivity perspective, the CGIAR's research in South Asia continues to be a sound investment, much as Raitzer and Kelley (2008) have shown at the global level.

Social impacts

Research has made important contributions to reducing poverty in South Asia, but it has done less well in reducing inter-household and inter-regional inequities. Often, favorable poverty impacts arise from the indirect benefits of increases in productivity, such as the reductions in food prices that arise from technologies that reduce farmers' growing costs per ton of output. Indirect growth benefits in the nonfarm economy are another example. Measured at these levels, agricultural research can be a cost-effective way of reducing poverty, both relative to other public investments and in terms of the cost per person raised out of poverty.

Within adopting regions, the impact evidence is more mixed and there is insufficient evidence to conclude whether or not the more deliberate targeting of agricultural research to the problems of poor households and women – including use of participatory research methods – is paying off. This is an area of impact assessment that warrants further attention, especially as the rural poor have diversified their livelihoods and are less easily helped through agricultural productivity growth.

Environmental impacts

There has been a rich research agenda targeting environmental problems associated with agriculture and a demonstrated potential for favorable impacts in farmers' fields. Many improved technologies and NRM practices are also win-win, in that they halt or reverse environmental problems while increasing yields and/or reducing modern input use and cost. Despite this, there are virtually no impact studies from South Asia that estimate a return to a research investment corrected for environmental costs and benefits. The closest is the Bantilan et al. (2005) study of ICRISAT's groundnut improvement technology for the semi-arid areas of India. The high internal rate of return of about 25% reported by Joshi and Bantilan (1998) in an earlier study is seemingly robust to within a percentage point or two, even when corrected for possible positive and negative environmental outcomes that affect yield and production costs (Bantilan et al., 2005). But 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. For example, the Kerr et al. (2000) study of watershed development projects in India. This may be the most that can realistically be hoped for, and if there were greater agreement on the environmental indicators to use it would be possible to at least allow for research investments to be ranked in different dimensions.

Given the popularity of alternative farming approaches and their competition for R&D funding, more rigorous assessments are needed. While their approaches seem to work well in LFAs, they have proved disappointing in GR areas. There is no evidence that organic farming or low external input approaches can match current high yields in GR areas whereas more precision approaches to modern inputs seem to offer significant steps in the right direction.

Another challenge facing researchers in South Asia is the generally poor adoption rates by farmers of many improved NRM practices that reduce environmental damage. There are several possible reasons for this, including high levels of knowledge required for their practice, perverse incentives caused by input subsidies, labor constraints and insecure property rights, difficulties of organizing collective action, and externality problems. Additional policy research on these issues might be able to help leverage additional impact from past and future technology research.

Policy impacts

A vast amount of policy research has been undertaken in South Asia since the GR, and several CGIAR centers have been active participants. Case studies show favorable returns to policy research, though the conditions under which it leads to policy change are not well understood. Additional policy research is needed to identify more practical solutions for overcoming some of the constraints to adoption of more environmentally favorable technologies and NRM practices.

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. Firstly, many more workers are going to have to exit from agriculture in South Asia as the economic transformation proceeds. Agriculture's share in GDP is already much lower than its employment share, implying that the average productivity of agricultural workers is already lower than that of nonagricultural 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 the farming activities of 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 have to 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 large 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 agricultural research in India, but this is an issue that warrants further study. A related issue stems from the observed decline in 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 are also needed to better understand the potential tradeoffs and complementarities between productivity, social, and environmental goals in agricultural research and for determining 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 that 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 the environmental indicators to use, then it would be possible to at least 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 mean and 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.

Finally, very little has been said in this report about regional spillovers and spill-ins from agricultural research in South Asia, yet these are important issues. IRRI, for example, does work on rice problems that cut across Asian rice systems, and much the same can be said about the commodity work of CIMMYT and ICRISAT. Shiferaw et al. (2004) have characterized some of these spillovers for South Asia, and Maredia and Byerlee (2000) have developed a model for quantifying their impacts, but still missing is a comprehensive analysis of their benefits and implications for calculations of the economic returns to agricultural research in South Asia.

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