



Consultative Group on International Agricultural Research
SCIENCE COUNCIL

**CGIAR and NARS partner research
in sub-Saharan Africa:
evidence of impact to date**

Mywish K. Maredea and David A. Raitzer

SCIENCE COUNCIL SECRETARIAT

October 2006

Consultative Group on International Agricultural Research
SCIENCE COUNCIL

**CGIAR and NARS partner research
in sub-Saharan Africa:
evidence of impact to date**

Mywish K. Maredia and David A. Raitzer

SCIENCE COUNCIL SECRETARIAT
October 2006

Mywish K. Maredia is Deputy Director, Bean/Cowpea CRSP and Adjunct Associate Professor of the Department of Agricultural Economics, Michigan State University.

David A. Raitzer was a consultant for the CGIAR Science Council and is presently a Research Impact Assessment Scientist, Center for International Forestry Research (CIFOR).

Contents

Foreword	vii
Acronyms	ix
Summary	1
1. Introduction	3
2. Study Framework	5
Inventory of <i>ex post</i> impact assessments	6
3. Tracing the Research-to-Impact Pathway for CGIAR Research in Sub-Saharan Africa	11
Review of CGIAR research inputs in sub-Saharan Africa	11
Adoption and potential impacts of CGIAR research in sub-Saharan Africa	15
Evidence of adoption and potential impacts of crop germplasm improvement research	18
Evidence of adoption and potential impacts of research other than crop germplasm improvement	24
4. Meta-Analysis of Benefits and Costs of CGIAR–NARS Research in SSA	29
Assessment of credibility	29
Transparency: criteria and indicators	29
Analytical rigor: criteria and indicators	30
Scenarios of the aggregation of research benefits	33
Scenario 1: ‘Potential’ benefits	33
Scenario 2: ‘Plausible’ benefits	33
Scenario 3: ‘Substantially demonstrated’ benefits	33
<i>Ex post</i> and <i>ex post</i> + <i>ex ante</i> sub-scenarios	34
Aggregation of costs and benefits: methodology	36
Estimating the share of sub-Saharan African benefits in global estimates	36
Estimating the costs of CGIAR centers	36
Estimating the costs of NARS partners	36
Deflation and discounting	38
Aggregation of costs and benefits: results	39
Results of the meta-analysis	39
Sensitivity analysis	42
Discussion of results	43
Impacts of crop germplasm improvement research	44
Impacts of new or improved agricultural inputs	44
Impacts of biological control research	47
Impacts of new or improved management practices on natural resource management	48
The missing impacts of research in the meta-analysis: what do they suggest?	49
Limitations of the benefit–cost meta-analysis	50

5. Recommendations for Future Assessment Activities by International Agricultural Research Centers and the Standing Panel on Impact Assessment	53
6. Conclusions	55
References	57
List of studies reviewed for meta-analysis	61
Annexes	63
Annex A: Bibliographic Information of <i>Ex Post</i> Impact Studies Included in the Database in Step 3	63
Annex B: Review and Adoption Studies Included in the Database in Step 3	69
Annex C: Rate of Return Studies Included in the Alston et al. (2000) Study: Characteristics and Comparison with the Studies Included in the Present Report	73
Annex D: Results of the Critical Review of 23 Impact Studies: Average Scores for Transparency and Analytical Rigor, and Implications for the Meta-Analysis	77

List of Figures

Figure 1.	Steps in the research-to-impact pathway	5
Figure 2.	Approach used in building the inventory and developing the database for the review and meta-analysis	6
Figure 3.	Total (core and restricted) CGIAR expenditures: systemwide and by sub-Saharan Africa region, 1972–2003	11
Figure 4.	Expenditures by CGIAR centers in sub-Saharan Africa, 2000-2004	13
Figure 5.	Percentage of total CGIAR budget expended on different program outputs, 2004	14
Figure 6.	Program expenditures by outputs by the CGIAR in sub-Saharan Africa, 1972–2002	14
Figure 7.	Share of CGIAR-related improved varieties and other sources of varieties in the total area planted to major food crops in sub-Saharan Africa, late 1990s	23
Figure 8.	Hierarchical relationship of principles, criteria, and indicators for assessing the transparency of reviewed studies	30
Figure 9.	Hierarchical relationship of principles, criteria, and indicators for assessing the analytical rigor of reviewed studies	31
Figure 10.	Comparison of estimated costs and documented benefits of joint CGIAR–NARS investment under three scenarios of aggregation of economic impact and two time periods	40
Figure 11.	Sensitivity of aggregated benefit–cost ratios to real discount rates under six scenarios	42
Figure 12.	Sensitivity of aggregated benefit–cost ratios to NARS costs under the ‘substantially demonstrated’ and ‘potential’ benefits scenarios	43

List of Tables

Table 1.	Profile of impact studies included in the relevant database (step 2)	8
Table 2.	Major research focus and activities of CGIAR centers in sub-Saharan Africa, 1970s–2004	12
Table 3.	Number of impact studies reviewed by indicators of output under five major CGIAR program agendas	16
Table 4.	Number of studies reviewed by technology and research focus	19
Table 5.	Evidence of impacts of CGIAR investments in research in crop germplasm improvement in sub-Saharan Africa	20
Table 6.	Adoption of improved varieties of major food crops in sub-Saharan Africa, late 1990s	22
Table 7.	Evidence of impacts of CGIAR research on technologies or outputs other than improved varieties	25
Table 8.	Principles, criteria, indicators and rating examples for evaluating benefit–cost studies	32
Table 9.	Number of studies included in the three scenarios of the meta-analysis	33
Table 10.	Studies and time period of estimates of benefits included in the three scenarios and two sub-scenarios of the meta-analysis	35
Table 11.	NARS costs as a percentage of CGIAR center costs in realizing benefits attributed to center investments: review of seven studies	37
Table 12.	Annual benefit and cost estimates for research investments of CGIAR–NARS partnerships under different scenarios of study selection	41
Table 13.	Potential aggregate estimates of benefits and periods of coverage of studies included in the <i>ex post</i> scenario	45

Foreword

Over its lifetime, the Consultative Group on International Agricultural Research (CGIAR) has invested 40% of its resources on research and capacity strengthening of agriculture in sub-Saharan Africa (SSA). While there are differing impressions of the impact of this investment on the livelihoods, health and prosperity of Africans, there has been no consensus on the issue, nor has a systematic, analytical attempt been made to obtain a clearer picture of the overall impact of the CGIAR in the region. Various stakeholders urged the Science Council's Standing Panel on Impact Assessment (SPIA) to do a more quantitative assessment of the impact of CGIAR investment in SSA as a follow-up to an earlier desk study of available evidence of such impacts (Gryseels and Groenewold, 2001). Mywish Maredia (team leader) and David Raitzer were contracted to undertake the study.

This study follows the meta-analysis process, and adopts the same general objectives that guided the meta-analysis of overall CGIAR costs and benefits by Raitzer (2003). The study is a form of break-even analysis that asks the question, "Can the benefits estimated in the limited number of credible impact assessments available to date justify the entire expenditure of the CGIAR in SSA?" If the answer is negative but benefits remain unquantified, there is a need to search for additional credible evidence of benefits. If the answer is positive, there is less need to search for additional evidence of benefits from an accountability perspective, but there is still a need for more assessments to be made across the full range of research and research-related activities to help inform future priorities.

Based on the review of the study results, SPIA derived the following conclusions from the assessment:

- Only a few credible impact assessment studies with plausible results have been carried out by the CGIAR–national agricultural research systems (NARS) in SSA. These assessments focus on two main research areas: biological control; and crop germplasm improvement (CGI). The economic benefits of biological control represent 80% of the total; and the benefits of CGI, most of the remainder.
- There is need for a more comprehensive coverage of other research themes in future impact assessments in SSA. Among these are breeding of improved varieties of cowpea, pigeonpea, plantain, soybean, sweet potato, and yam; genetic improvement of fish; natural resource management (NRM); biodiversity; enhancing governance; improving policy; and strengthening NARS. In some cases, many studies of the dynamics and determinants of adoption are either completed or underway, and need to be systematically analyzed, synthesized, scaled up and extended by the centers into comprehensive impact assessment studies.
- By 2004, a small number of successful projects which had impressive documented impacts and representing only 5% of CGIAR–NARS total research investments in SSA, had recovered the entire cumulative investment of these institutions over a period of 35 years. A projection of benefit flows for these same successful projects beyond 2004 shows that only 5% of CGIAR–NARS research investments could generate more than US\$1.5 in benefits for every US\$1 invested.
- The probable actual benefits from CGIAR–NARS investment in the region are likely to be much higher than those calculated using just the few documented major research successes. This is because selected impact studies represent less than 7% of the 367 studies reviewed by the authors.
- Very few studies that measure or document the social, equity, environmental, or health impacts of agricultural research were found. This is not peculiar to the SSA region, but represents the profile of impact assessment literature globally and reflects the fact that the methodology for quantifying productivity impacts of research outputs/outcomes is much more advanced than quantifying other types of research impacts.

SPIA recognizes the limitations of the study, most of which are discussed by the authors. The possible negative impacts associated with the research investments were not analyzed, since the focus was only on economic impacts. The assessment did not include spill-overs to and spill-ins from other regions; figures available on the costs incurred by NARS partners in the above research were difficult to estimate. The perceived but not-included benefits from CGIAR partner research are substantial and are likely to change the results of the study by making the calculated benefit-cost ratios (BCRs) represent lower-bound estimates.

This assessment represents the first phase of an overall initiative by SPIA to assess impacts of CGIAR research in various regions. It responds to the need for accountability at the regional level, both to donors and to regional members, stakeholders, and clients.

In early 2005, SPIA decided to conduct scoping studies for each geographic region where CGIAR research is carried out, starting with SSA. Following this, it would consider the results of each study, and then decide if a second, more detailed study was needed and, if so, what priority it should be given in terms of the overall regional impact assessment initiative and SPIA's work plan, given the limitations in budget and capacity. Given the results of the scoping study for SSA, and the considerably higher costs involved in further assessment that would involve primary data collection in the region, SPIA came to the following conclusions:

- CGIAR centers need to be strongly encouraged to undertake higher-quality *ex post* impact assessments of all their major research and that of their NARS partners in SSA. These assessments should build upon the numerous adoption studies that have been or are being done.
- SPIA should give priority to initiating a scoping study in another region in 2006, and revisit the impact assessment needs of SSA when centers have higher quality and comprehensive impact assessments for the region.
- For a possible next round of center-based impact assessments, SPIA is willing to work with centers in selecting a complementary set of research projects or programs focused on SSA.

SPIA wishes to thank the study team for a thorough and enlightening overall assessment based on the available scattered evidence of the impacts of the CGIAR in SSA.

Hans Gregersen
Former Chair
CGIAR Science Council,
Standing Panel on Impact Assessment

Jim Ryan
Current Chair
CGIAR Science Council,
Standing Panel on Impact Assessment

Acronyms

BCR	benefit–cost ratio
CGI	crop germplasm improvement
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
CIFOR	Center for International Forestry Research
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center)
CIP	Centro Internacional de la Papa (International Potato Center)
GIS	geographical information system
ha	hectare
IAA	integrated aquaculture/agriculture
IBPGR	International Board of Plant Genetic Resources
ICARDA	International Center for Agricultural Research in the Dry Areas
ICLARM	International Center for Living Aquatic Resources Management
ICRAF	World Agroforestry Center
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IIMI	International Irrigation Management Institute
IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Center for Africa
ILRAD	International Laboratory for Research on Animal Diseases
ILRI	International Livestock Research Institute
INIBAP	International Network for Improvement of Banana and Plantain
IRRI	International Rice Research Institute
IPGRI	International Plant Genetic Resources Institute
IPM	integrated pest management
IRR	internal rates of return
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
IWMI	International Water Management Institute
NARS	national agricultural research systems
NGO	non-governmental organization
NRM	natural resource management
SPIA	Standing Panel on Impact Assessment
SSA	sub-Saharan Africa
WARDA	Africa Rice Center (formerly West African Rice Development Association)

Summary

Sub-Saharan Africa (SSA) is a region better known for its food security failures than its successful development initiatives. In this context, the contributions made by the Consultative Group on International Agricultural Research (CGIAR) and its partners (principally, national agricultural research systems (NARS)) in the region to benefits generated for farmers, consumers, and the environment, are often overshadowed by negative or stagnant overall trends. As a result, this analysis attempts to identify, assess, and synthesize available evidence on the impact of agricultural research, so as to offer a systematic answer to the question: “Have the investments made by CGIAR–NARS in SSA been justified by documented benefits to date?”

To answer this question, a comprehensive inventory of all impact assessments of research outputs attributable in part to the CGIAR system in SSA was made. This inventory identified hundreds of studies of technology adoption, although the vast majority turned out to be small-scale studies of adoption dynamics. A smaller body of literature was also identified for aggregate areas of adoption, and these studies illustrate large areas of adoption of crop varieties derived from improved germplasm. In aggregate, these studies estimate that over 11 million hectares (ha) are currently planted to CGIAR-derived varieties in the region. However, apart from adoption of improved varieties or biocontrol, there are few cases where adoption of research outputs has progressed beyond tens of thousands of hectares.

In order to quantify the aggregate economic benefits stemming from CGIAR–NARS research in SSA, a meta-analysis approach was taken. Twenty-two studies were identified for the calculation of aggregate rates of return for CGIAR and partner investments in the region. These studies have were then appraised against a review framework consisting of principles, criteria, and indicators for study rigor. The economic benefits reported by studies were then grouped on the basis of analytical rigor, and then aggregated and set against total investment by the CGIAR–NARS to determine if the total investment to date is justified under a range of assumptions.

The study found that aggregate investment is justified under a fairly wide range of suppositions, provided that benefits continue at their reported levels beyond 2004 (*ex post + ex ante* scenario). If only reported benefits up to 2004 are included (*ex post* scenario), the benefit–cost ratio (BCR) falls to less than unity for the most conservative meta-analysis category of substantially demonstrated benefits. However, a number of studies only calculate a single year of annual research benefits when benefits have been observed to continue for a number of years; therefore, this treatment is probably excessively conservative. Under the less conservative assumptions about benefit duration (*ex post + ex ante*) aggregate BCRs range between 1.12 and 1.64.

Under all meta-analysis scenarios, the vast majority of documented benefits stem from a relatively limited array of activities. Biological control results in more than 80% of all benefits in all scenarios. More than 90% of these biological control benefits are attributed to control of the cassava mealybug. Close to 20% of total benefits result from the genetic improvement of crops, and less than 1% result from all other activities. The benefits included for crop germplasm improvement (CGI) represent the impacts realized over different time periods on 8.9 million ha (out of 11 million ha) planted to CGIAR-related varieties in the late 1990s.

It is an impressive achievement that aggregate documented benefits well exceed CGIAR–NARS investment in SSA. However, there remains significant scope to estimate the benefits from agricultural investments in the region. A substantial proportion of documented wide-scale and long-term adoption of improved varieties has never been subject to rigorous impact assessment. For example, the included benefits from more than one-half of the 8.9 million ha planted to CGIAR-related varieties represent benefits from only one year of adoption data. Appropriate methods are also currently being developed for other portions of the CGIAR portfolio. Thus, in time, even the most generous of the aggregate ratios reported here should prove to be an underestimate, provided that additional effort is invested in further assessment.

I. Introduction

The Consultative Group on International Agricultural Research (CGIAR) was established in 1971 to mobilize agricultural science and provide financial support to address widespread food insecurity problems in many developing countries. Since its establishment, the CGIAR system has invested more than US\$7 billion in various research and development activities related to poverty, resources conservation, and nutrition. Over the years, several studies have documented the track record of CGIAR researchers in delivering results that improve people's lives and help protect the environment (Pingali, 2001; Gardner, 2003). In recent years, the Standing Panel on Impact Assessment (SPIA) has sponsored several studies to document the impacts of CGIAR centers at a system level. These studies provide clear evidence that the investments made by the CGIAR have been productive. For example, a recent meta-analysis study of the aggregate costs and benefits of the CGIAR system shows a benefit–cost ratio (BCR) in excess of one (Raitzer, 2003). The comprehensive systemwide study by Evenson and Gollin (2003) on the impacts of crop germplasm improvement (CGI) research contends that in its absence, world food production would have been 4–5% lower in developing countries, and 13–15 million more children would have suffered from hunger and malnourishment.

While the global impacts of agricultural research carried out by the centers have been relatively well documented, clear evidence of CGIAR regional impacts, especially in sub-Saharan Africa (SSA), is less apparent. The meta-analysis study of rates of return by Alston et al. (2000) documents 47 studies of impact assessment in SSA based on a survey of literature between 1958 and 1997. Only four out of these 47 studies assess agricultural research that was primarily conducted by a CGIAR center (Alston et al., 2000). The other studies are classified as research conducted by governments (40), universities (1), or others (2). It is very likely that many of the studies conducted by governments or others may have indirectly benefited from CGIAR research but, with only 4 out of 47 studies actually classified as research performed by a CGIAR center, it is clear that the evidence of CGIAR research impacts in SSA is not well documented.

Since its inception 35 years ago, it is estimated that about 41% of CGIAR resources have been allocated to solving problems specific to the needs of the SSA region. In the face of several well-documented failures of new technologies (Carter, 1995), donors continue to raise questions about the value added by the CGIAR system in SSA. Yet, case studies and regional overviews conducted in the recent past do provide evidence that the CGIAR and its partners have made substantial contributions to agricultural development in Africa¹ (Gryseels and Groenewold, 2001). However, much work remains to be done before a clear, quantitative and more comprehensive picture of the impact of the CGIAR investment in SSA emerges.

This study represents the first phase of an overall initiative by SPIA to assess impacts of CGIAR research in SSA. The overall initiative relates to the need for accountability at the regional level, both to donors and clients. As a phase I study, the aim of this report is to fill some of the knowledge gaps by undertaking a rigorous and comprehensive documentation, synthesis and assessment of the available evidence on the impacts of new technologies and improved policies as a result of research investment by CGIAR–NARS (national agricultural research systems) partnerships in SSA. The study aims to:

1. Build a systematic and comprehensive inventory of all the available *ex post* impact assessments of agricultural research done by CGIAR–NARS partnerships in SSA.

¹ Unless specifically stated otherwise, the term 'Africa' in this paper refers to sub-Saharan Africa.

2. Critically review this collection of impact studies and document data pertaining to the methodology used, impact indicators, adoption rates, internal rates of return (IRR), household income effects, gender implications, policy assessment, and other factors.
3. Analyze the data with the aim of providing a more complete understanding of the impacts of agricultural research.
4. Determine the additional efforts needed to better document the contributions and impacts of CGIAR–NARS research (i.e. make recommendations for a possible phase II of the overall SPIA initiative).

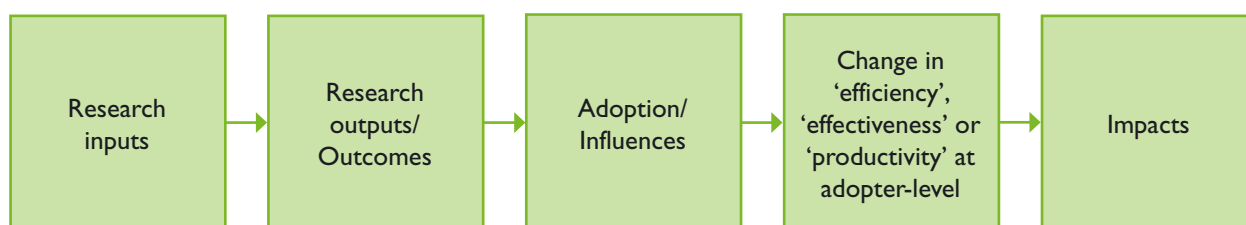
The relationship between the CGIAR and NARS worldwide has changed significantly since the CGIAR was founded in 1971 (Gardner, 2003). In SSA (as well as other regions) there are two distinct types of relationship. For one group of countries, mainly large ones such as Kenya and Nigeria, the role of the CGIAR has changed from that of mentor to NARS and other research and development agencies to that of a partner and facilitator. For the other group of countries, mainly smaller, poorer ones, where both NARS and the private sector are weak, the CGIAR still plays a mentorship role. In either case, the specific contributions of the CGIAR cannot be rigorously separated from those of NARS. Nearly all CGIAR research results, outputs and products are disseminated to end users through partnerships that have been created between CGIAR, NARS, advanced research institutes, and extension specialists in these countries. Thus, although the focus of this study is on the resources invested by the CGIAR system, references made to the contributions of the CGIAR are those of a partnership. In the quantitative analysis of costs and documented benefits presented here, the corresponding NARS and other partner costs are estimated and included to reflect this partnership and joint ownership of realized benefits.

This report begins by discussing the framework used to document, synthesize, and assess the evidence of impacts. This is followed by a description of the methods of identifying and building an inventory and database of impact studies, along with the content and profile of this database. Next comes documentation of evidence of the impacts of CGIAR research in SSA. This is based on sampling the database of major outputs of CGIAR research in SSA, indicators of change in productivity, adoption of technology, and impacts. The next section describes the application and results of the meta-analysis framework used to synthesize the evidence of economic impacts. The final section provides conclusions, which draw upon the results of the literature review and the meta-analysis. The shortcomings of this study are also discussed and some recommendations for future action by the CGIAR and SPIA are made.

2. Study Framework

The organizational framework used to document, synthesize and assess the available evidence on the impacts of research in SSA follows the generalized steps of the simplified research-to-impact pathway presented in Figure 1.² The term ‘research inputs’ refers to the efforts and total resource investments (human, financial, and physical) to which the outputs and, ultimately, the impacts are attributed. Documenting the research inputs is the first step in this impact assessment. The most common measure of research inputs that is documented is financial investment (in monetary units). These are considered as the costs against which the benefits of research (impacts) are compared in order to assess the returns on research investment.

Figure 1. Steps in the research-to-impact pathway



The second step is to identify and document research outputs or outcomes.³ These can be tangible (e.g., a new variety) or non-tangible (e.g., a new method or a new policy recommendation) outputs or outcomes. A requirement, however, is that the research outputs must be improved compared with previously available technologies or practices. In order to have recognized impacts, research outputs must result in a change in efficiency, effectiveness, productivity, risk, sustainability, or distribution of benefits from the system in which they are used. Documented adoption of research outputs by end users is a necessary, but insufficient indicator of impact, if these consequences are not analyzed. Assessing the change in efficiency and productivity measures at the adopter level (e.g., farm-level impacts) and estimating the adoption of research outputs are two key intermediary steps before the impacts of research can be assessed against a counterfactual scenario (a scenario without the research-derived intervention). A necessary step in impact assessment is the quantification and aggregation of positive and negative benefits attributed to the research output and its adoption. This is achieved by comparing the levels of benefits that have been realized with those that would have occurred in the absence of the assessed research. These benefits (positive and negative) include environmental, social, economic, and health benefits. Thus, the last step – assessment of research impacts – can take many forms depending on the type of research output and the objectives of the study. However, the methodology for quantifying economic benefits from yield changes is much more advanced than for quantifying other types of impacts. The quantified benefits (net of all negative benefits) are often compared with measures of research inputs to produce indicators of impacts that can be compared across investment portfolios.

² Although Figure 1 is linear and has only five general steps, such simplistic representation is for illustrative purposes only. It is recognized that many impact pathways may involve considerably more steps and iterations. For example, policy-oriented research outputs are not directly adopted, but can exert influence on decision-making in ways that may affect the effectiveness of government actions.

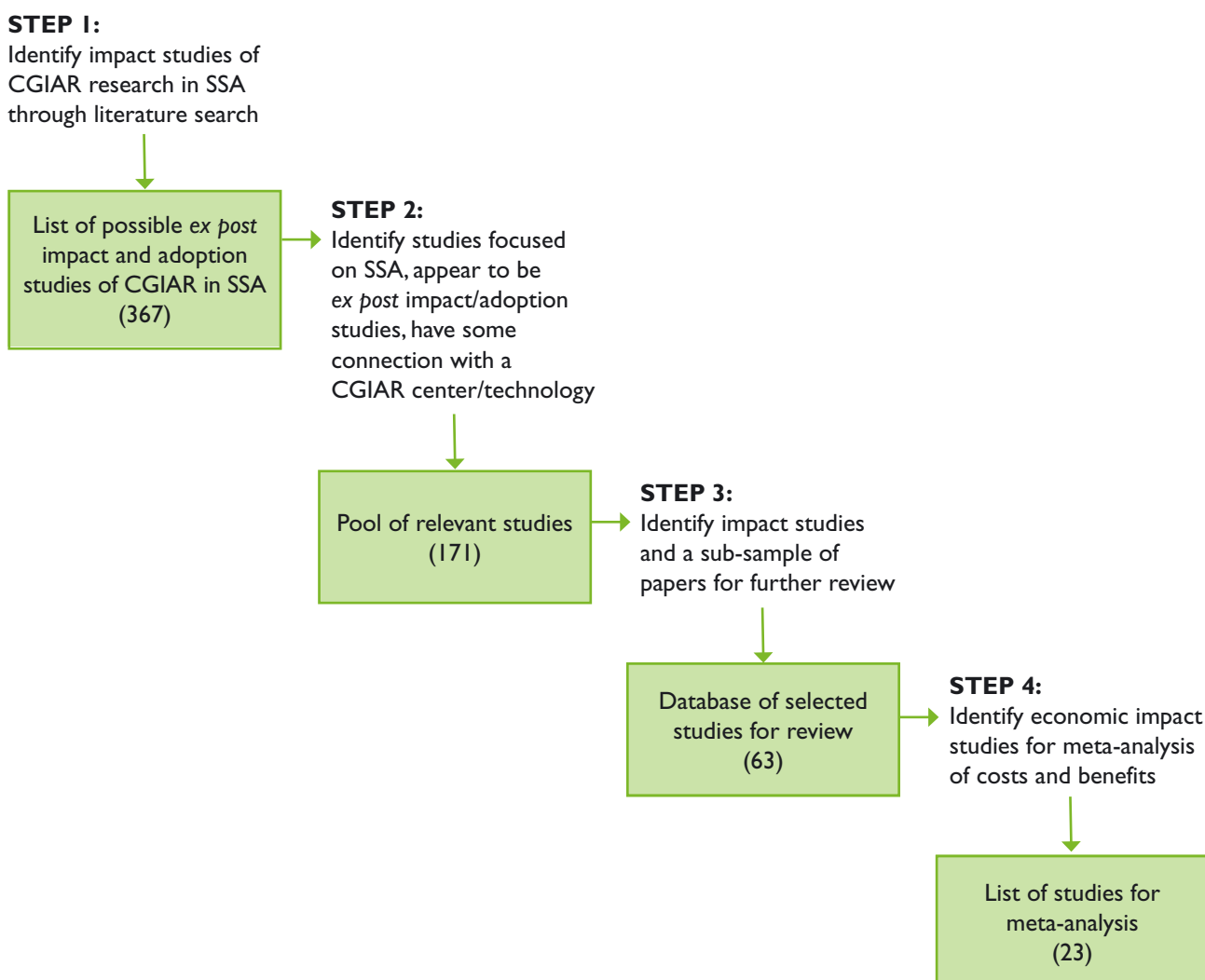
³ While the research outputs referred here are adoptable research products, it is recognized that there are often a series of intermediate outputs and adoption events within the broader research and development process. For example, research by a CGIAR Centre may result in an improved breeding technique which can be applied by plant breeders worldwide in the breeding of improved varieties to be adopted by farmers.

Studies that assess impacts of research have to estimate and document all the intermediary steps of the research-to-impact process. However, there are numerous studies that only document evidence of intermediary steps but do not assess the impacts. This study inventories all of the *ex post* impact studies of CGIAR research with the aim of identifying studies that fall into each of these different steps of the impact pathway. Thus, although the main objective of this report is to assess and document impacts, a synthesis of evidence from sample studies that fall into the other steps (research outputs, and change in productivity and adoption) is also given. The report thus gives a general overview of the evidence found in the literature of CGIAR impacts in SSA along with the whole research-to-impact pathway.

Inventory of *ex post* impact assessments

Figure 2 presents the overall approach that was used to build the inventory and develop the database of selected studies. It is essentially a four-step process that involves performing a literature search (step 1); identifying relevant studies (step 2); selecting appropriate studies for review (step 3); and performing the meta-analysis (step 4).

Figure 2. Approach used in building the inventory and developing the database for the review and meta-analysis



Step 1: The following sources of information were used to develop a comprehensive inventory of possible CGIAR-center *ex post* impact and adoption studies in SSA: 1) the impact website of the CGIAR (<http://impact.cgiar.org/>); 2) a literature search using web-based databases; and 3) verification and further additions to the list given by respective CGIAR centers.

Step 2: The initial inventory contained a list of 367 studies⁴. However, upon closer scrutiny, many of these studies were found to be irrelevant to the objectives of this study. The authors further filtered the list and classified 171 studies as relevant for further review.

Table 1 gives a summary profile of the 171 relevant studies that form the population of this assessment. These studies are attributed to 12 CGIAR centers and their NARS partners. A large number of studies are attributed to three commodity-focused centers – Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT; the International Maize and Wheat Improvement Center), the Africa Rice Center, formerly West African Rice Development Association (WARDA), and the International Institute of Tropical Agriculture (IITA). This is not surprising, since these centers have exclusive (WARDA and IITA) or major (CIMMYT) mandates for agricultural research in SSA. The relatively large number of studies focusing on West and East Africa also reflects the geographic mandates of these three centers. A number of studies included in this database are also global impact studies that specifically identify the regional impacts of CGIAR research in SSA as part of the global assessment.

Out of the total 171 relevant studies, a majority (107) assess adoption of research outputs or technologies. In terms of types of impacts assessed, very few studies measure the social, equity, environmental, or health impacts of agricultural research. This is not a unique feature of impact studies in the SSA region, but represents the profile of the impact assessment literature globally. It reflects the fact that the methodology for quantifying productivity and income outputs is much more advanced than that for quantifying other types of research outputs.

The following should be noted regarding the database of relevant studies:

- The list includes all studies that, based on the cursory review of the title and/or summary, appear to be *ex post* impact assessment studies of research done by the CGIAR and its NARS partners.
- The authors have made no attempt to further reduce this list to avoid duplication of some studies that may have been published in different forms (e.g., as a CGIAR center working paper or journal article), or studies that review papers based on other impact case studies. Hence, studies dealing with the same case or example of a technology may be duplicated if published via several outlets.⁵

Based on these two disclaimers, the authors believe that this initial database actually includes more studies than would potentially qualify as *ex post* impact case studies of CGIAR research in SSA.

Step 3: Given the limited timeframe for conducting this study and the disclaimers noted above, the authors identified a smaller set of the adoption and impact studies inventoried in the database. The selection criteria for the sub-sample were based on the type of study and its availability or accessibility to the authors. The goals were to: 1) include as many studies as possible that documented large-scale adoption

⁴ Although this study attempts to assess the impacts of CGIAR–NARS research in SSA, the main focus is primarily on impacts of technologies, outputs or outcomes that can be clearly attributed, at least in part, to the CGIAR. Thus, impact studies of NARS outputs, outcomes or technologies were not targeted in this search. It is possible that due to this primary focus on CGIAR impact studies, the authors may have missed some impact assessments conducted by NARS partners on technologies that may have been derived from CGIAR input.

⁵ The database in step 2 included around 30 studies that were either duplicative or were reviews of previous impact case studies. In subsequent steps, duplicative studies were excluded from the review process.

Table 1. Profile of impact studies included in the relevant database (step 2)

Number of studies on research conducted by CGIAR–NARS in SSA by center	
CGIAR center^a	Number of studies
WARDA	39
IITA	34
CIMMYT	30
ICRISAT	17
ICRAF	15
CIAT	11
CIP	8
ILRI	8
WorldFish	3
IFPRI	2
Other (i.e. SPIA and collaborative research support programs)	2
ICARDA	1
IPGRI	1
Total	171
Number of studies by geographic focus^b	
Region	Number of studies
West Africa	72
East Africa	43
Southern Africa	19
Central Africa	9
Continent-wide	14
Global (Africa as one of the regions)	20
Number of studies by types of impacts assessed^c	
Impact type	Number of studies
Adoption	107
Productivity	81
Equity	7
Social	7
Other (environment, health, policy, or training)	12

^a For an explanation of acronyms see acronym list, page viii

^b Some studies may focus on more than one region.

^c Some studies may assess more than one type of impact.

and assessed economic, social, environmental, and other impacts, and a sample of review papers that provided summary assessment of impacts or adoption of specific technologies; and 2) weed out studies that were small-scale adoption studies, were duplicative, were difficult to access due to incomplete citation information in the database, or were listed as unpublished reports or mimeos. Based on these criteria, the

review list was reduced to 63 studies: 52 impact studies and 11 review or adoption papers. Annexes B and C list these studies and provide summaries of relevant information.

The following are some of the key observations made on the adoption and impact assessment literature.

1. A majority (about two-thirds) of the studies assessed impacts of CGI research performed by CGIAR–NARS partnerships. Ten percent of the studies dealt with environment-protection technologies. Only two studies dealt with the assessment of research that improves policies or strengthens NARS.
2. About 41% of the studies in the database were published in peer-reviewed journals or as book chapters; 37% were published as center publications, and the remaining 22% were either conference and workshop papers or unpublished reports.
3. In terms of impact assessment studies by region, about 46% of the studies focused on adoption or impact assessment in West and Central Africa, and 37% on East and southern Africa. A few studies (17%) were either global or focused on the entire African continent.
4. The highest percentage of studies (42%) assessed impacts at a micro level in a particular country. Studies assessing macro-level impacts a country, region, or continent were relatively few (12%, 19%, and 8%, respectively).
5. More than half (28) of the 52 impact studies documented adoption and/or farm-level impacts of agricultural research. Some 24 studies documented the **aggregate benefits** for a year or a given time period.

Step 4: The analysis focused on a critical review of 23 of the 24 studies that documented aggregate benefits of CGIAR–NARS research in SSA. To make sure that this subset of 23 studies did not overlook any major impact study of CGIAR research in SSA, this list was verified against the list of 47 rates of return studies for SSA documented by Alston et al. (2000) (see Annex A).⁶ Six studies were found common to both the lists – four studies that were classified by Alston et al. (2000) as assessment of research performed by a CGIAR center in SSA, and one each by a government or other organization. The other 41 studies in the list could not be explicitly attributed to the CGIAR and hence were excluded from the database. Of the 23 studies included in this work, the 17 that are not part of the meta-analysis by Alston et al. are all studies conducted or published after 1997.⁷

The review process is based on the framework of principles, criteria, and indicators for study credibility given in Raitzer (2003), which is derived from a selective review of the methodological literature. On the basis of the assessment of individual impact studies against this framework, three basic categories of benefit aggregation were constructed – potential, plausible, and substantially demonstrated. Benefits documented in the reviewed studies were then aggregated for each of the three categories and compared with total investment by the CGIAR–NARS partnership.

⁶ The CGIAR centers with substantial involvement in SSA were also contacted to verify this list to make sure no major studies of aggregate impacts were missed. The Centro Internacional de Agricultura Tropical (CIAT; International Center for Tropical Agriculture) has recently completed a major study of impact assessment of bean research in eastern and southern Africa. However, this study was not published by the time this report was completed and hence not included in the review and meta-analysis. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) brought to the authors' attention additional impact studies, two of which appeared appropriate (but small-scale) studies based on their titles. However, they were not accessible and hence not included in the review by the time this report was submitted. Other than these exceptions, no major impact studies that met the review criteria were identified by the CGIAR centers for inclusion.

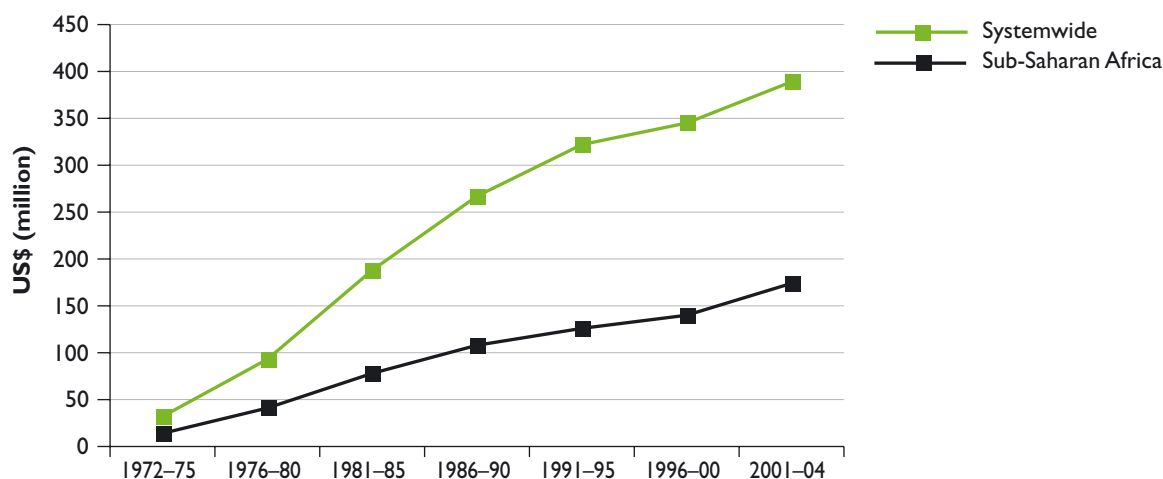
⁷ Evenson (2001) also provides a comprehensive list of rate-of-return studies globally. A quick review of this list also confirmed that there were no major CGIAR impact studies in SSA that were overlooked by this study.

3. Tracing the Research-to-Impact Pathway for CGIAR Research in Sub-Saharan Africa

Review of CGIAR research inputs in sub-Saharan Africa

Since its inception, the CGIAR has invested more than 40% of its annual budget in developing SSA agriculture. In nominal dollars⁸ (i.e. the value of the dollar at that time), this amounted to US\$14 million out of the US\$32 million annual total expenditure of the CGIAR system in the early 1970s; and US\$174 million out of the US\$389 million annual total expenditure in the early 2000s (Figure 3). In 2004, it was estimated that since its inception the CGIAR had invested more than US\$3.2 billion in nominal dollars (US\$4.3 billion in real dollars) in SSA.

Figure 3. Total (core and restricted) CGIAR expenditures: systemwide and by sub-Saharan Africa region, 1972–2003



Source: CGIAR Financial Reports (various)

The CGIAR originally consisted of four agricultural research centers: CIMMYT, the International Rice Research Institute (IRRI), IITA, and the Centro Internacional de Agricultura Tropical (CIAT; International Center for Tropical Agriculture). Only one of these centers (IITA) had headquarters in SSA. Today, there are 15 CGIAR centers⁹ conducting research on a variety of issues worldwide. Four of these centers, the World Agroforestry Center (ICRAF), the International Livestock Research Institute (ILRI), WARDA, and IITA, have their headquarters in the region; and the other 11 centers have some degree of involvement in the region. CGIAR center involvement in SSA ranges from devoting less than 5% of annual budget (IRRI), to almost 100% (WARDA and IITA) (Table 2). Centers that are based in other regions but have major involvement in SSA, as reflected by the share of their annual budget expended for SSA in 2000–2004, include CIMMYT (37%); International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

⁸ Unless otherwise specified, all amounts quoted in this document are in nominal US\$. Unless otherwise specified, amounts quoted in real dollars are in US\$₂₀₀₄.

⁹ This does not include ISNAR, which was dissolved in 2004 and became a division of IFPRI. However, the budget figures and related discussion in this paper, which is based on data up to 2004, includes ISNAR as one of the centers.

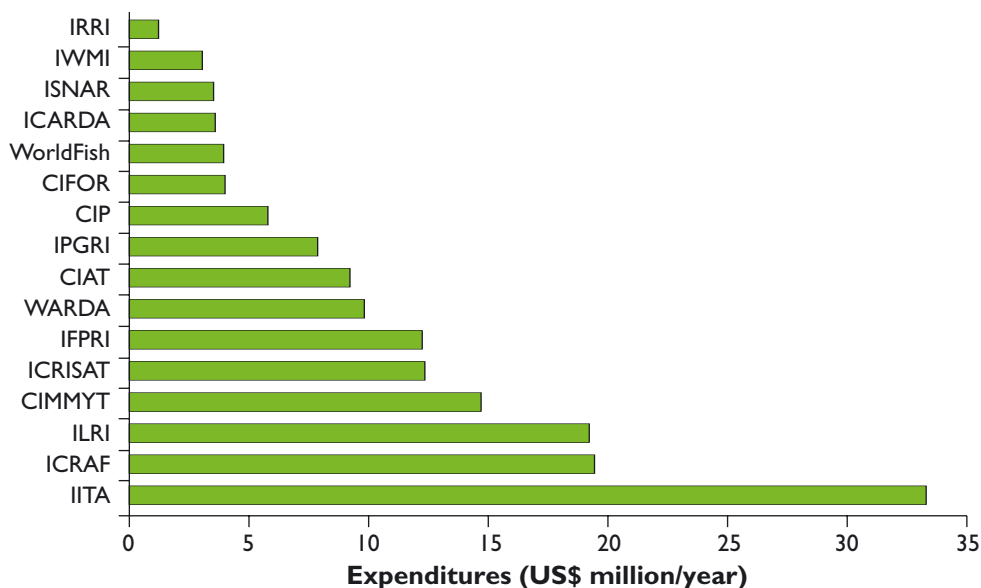
Table 2. Major research focus and activities of CGIAR centers in sub-Saharan Africa, 1970s–2004

No.	Center ^a	Year joined CGIAR	Current name/status	Major focus/activity ^b	Major involvement in SSA			Resources devoted to SSA as a percentage of total budget (2000–2004)
					1970s	1980s	1990s	
1	CIAT	1971	Same	Beans, cassava, tropical forages, rice, forest margins, savannas, and fragile African and Asian environments	×	×	×	29%
2	CIMMYT	1971	Same	Wheat, maize, and triticale	×	×	×	37%
3	IITA ^c	1971	Same	Soybean, maize, cassava, cowpea, banana, plantain, yams, and sustainable production systems for the humid low-land tropics	×	×	×	99%
4	IRRI	1971	Same	Rice and rice-based ecosystems				4%
5	ICRISAT	1972	Same	Sorghum, pearl millet, finger millet, chickpea, pigeonpea, groundnut, and sustainable production systems for the semi-arid tropics	×	×	×	50%
6	CIP	1973	Same	Potato and sweet potato	×	×	×	30%
7	ILRAD ^c	1973	ILRI (formed in 1995) ^c	Animal diseases	×	×	×	66% ^d
8	IBPGR	1974	IPGRI	Plant genetic resources of crops and forages, collection, and gene pool conservation	×	×	×	30%
9	IFPRI	1974	Same	Socioeconomic research related to agricultural development	×	×	×	49%
10	ILCA ^c	1974	ILRI (formed in 1995) ^c	Livestock feed and production systems	×	×	×	66% ^d
11	ICARDA	1975	Same	Wheat, barley, chickpea, lentil, faba beans, pasture, forage legumes, and small ruminants			×	15%
12	WARDA ^c	1975	Africa Rice Center	Rice production in West Africa	×	×	×	100%
13	ISNAR	1980	Dissolved and became a division of IFPRI (2004)	Strengthening national agricultural research systems	×	×	×	44%
14	ICRAF ^c	1991	World Agroforestry Center	Agroforestry and multi-purpose trees		×	×	80%
15	IIMI	1991	IWMI	Irrigation and water resources management		×	×	18%
16	ICLARM	1992	WorldFish Center	Sustainable aquatic resource management		×	×	30%
17	INIBAP	1993	INIBAP became a program of IPGRI (1994)	Bananas and plantains		×	×	—
18	CIFOR	1993	Same	Sustainable forestry management		×	×	30%
Resources expended to SSA in a given time period (US\$ million/year):					24	86	132	168
Resources expended to SSA as a percentage of total CGIAR expenditures:					44	41	40	44

^a For an explanation of acronyms see acronym list, page viii. ^b Activities targeted for SSA region are in green font; ^c Centers with headquarters in the SSA region; ^d Percentage share represents the budget of ILRI in 2000–2004.

(50%); the International Food Policy Research Institute (IFPRI) (49%) and International Service for National Agricultural Research (ISNAR) (44%). In absolute terms, the resources devoted by different centers to SSA between 2000 and 2004 range from US\$1.2 million by IRRI, to US\$33.3 million per year by IITA (Figure 4). IITA is by far the largest contributor in the CGIAR system to agricultural research and development efforts in SSA. Other centers that invest significant resources in SSA include, ICRAF at US\$19.4 million per year; ILRI at US\$19.2 million per year; CIMMYT at US\$14.7 million per year; and WARDA at US\$9.9 million per year (Figure 4).

Figure 4. Expenditures by CGIAR centers in sub-Saharan Africa, 2000–2004



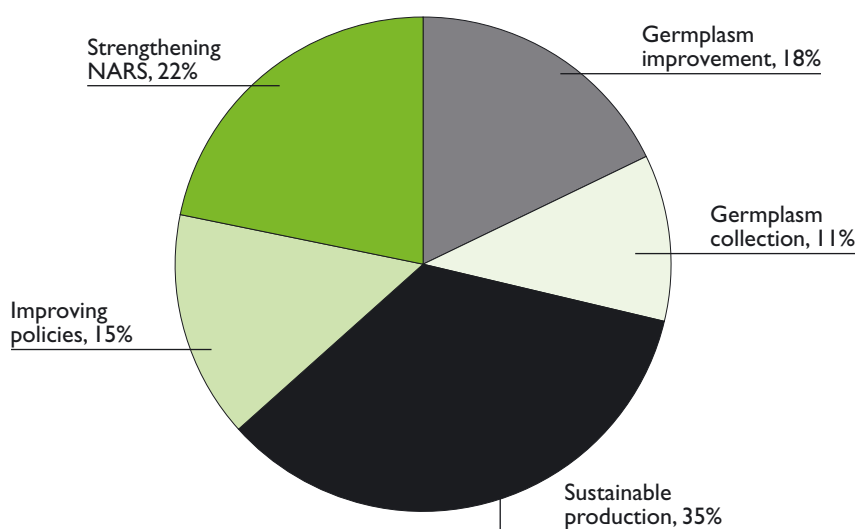
Source: CGIAR Financial Reports (2004)

CGIAR research in SSA focuses on the full range of the system’s global research portfolio encompassing genetic improvement of food crops, ruminant livestock, trees and fish, and integrated natural resources management, including biodiversity research, policy research, and capacity building. Budget data on how each CGIAR center allocates its resources to each of these activities in SSA are not available. However, the data presented in Figure 5 on the 2000–2004 percentage share of total CGIAR expenditures on outputs such as germplasm improvement, germplasm collection, sustainable production, improving policies, and strengthening NARS, are a good indicator of resource allocation. The majority of resources within that period were devoted to research activities that promote sustainable production (35%), strengthen NARS (22%), promote germplasm improvement (18%), improve policies (15%), and promote germplasm collection (11%).

Prior to 2003, the categories of program outputs reported included increasing productivity (germplasm improvement), protecting the environment, biodiversity conservation, improving policies, and strengthening NARS.¹⁰ Applying the systemwide percentage share data from 1972 to 2002 to these categories of program outputs for the same time period gives an indicator of resources expended in the region on different outputs over time (Figure 6). It is worth noting that activities focusing on increasing

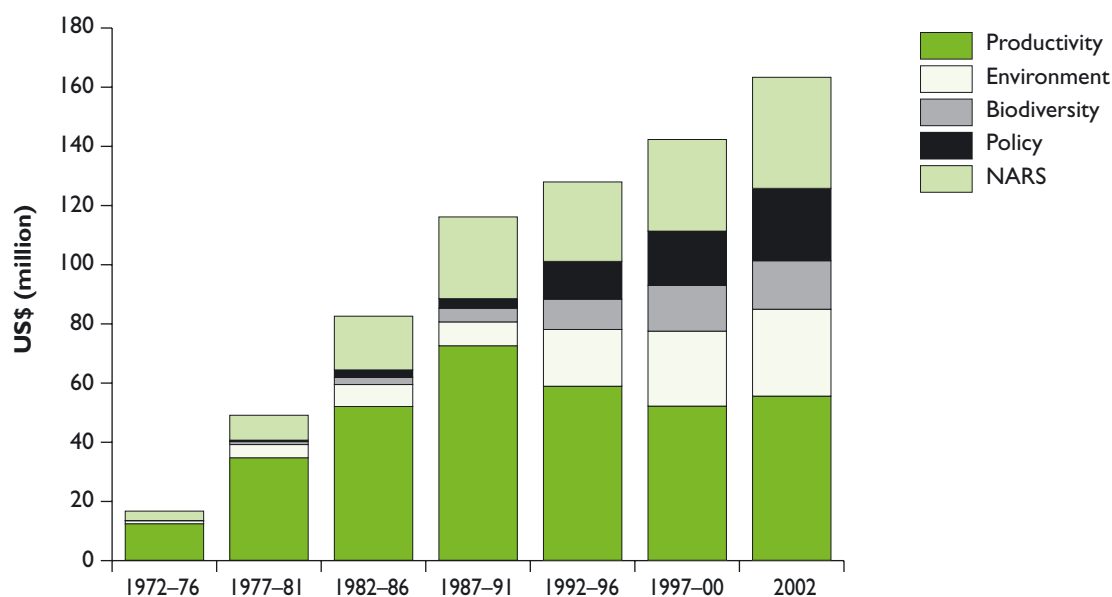
¹⁰ The discussion in this paper of research inputs, outputs and impacts is based on this general framework of research agenda output categories, which is used by the CGIAR centers for reporting purposes. However, we recognize that these and the more recent categories of research outputs (Figure 5) are not mutually exclusive. Research targeted by a center towards an agenda (e.g., improving policies) may contribute to several outputs (e.g., strengthening NARS and protecting the environment).

Figure 5. Percentage of total CGIAR budget expended on different program outputs, 2004



Source: CGIAR Financial Reports (2004)

Figure 6. Program expenditures by outputs by the CGIAR in sub-Saharan Africa, 1972–2002



Source: Calculated by authors based on percentage share of each program agenda in total CGIAR expenditures

productivity were dominant in the program agenda in the first two decades. However, in subsequent decades, resources devoted to increasing productivity declined both in absolute terms (from US\$74 million per year in the late 1980s to US\$55 million per year in 2002) and in relative terms (from 63% of total expenditures to 34% in the same time period). Strengthening NARS, has remained an important objective throughout the existence of the CGIAR. The system has consistently devoted about 20–22% of its total annual expenditures to this program output. Additionally, efforts towards improving policies, biodiversity conservation, and protecting the environment or natural resources have increased over time. In 2002, more than 40% of the total CGIAR system budget (US\$70 million) was spent on these three program outputs.

Adoption and potential impacts of CGIAR research in sub-Saharan Africa

Achievements of the CGIAR system in SSA have been the subject of several reviews in the past (e.g., Gryseels and Groenewold, 2001; Eicher and Rukuni, 2003). This section summarizes the adoption of major outputs directly attributed to CGIAR–NARS partnerships in SSA and their potential impacts. The focus is on research occurring specifically on SSA and not on spill-overs from global efforts. Similarly, spill-over effects of SSA-specific research into other regions, and NARS-exclusive research are excluded from this review.¹¹

This discussion is organized by the five program goals of the CGIAR system: increasing productivity; protecting the environment; biodiversity conservation; improving policies; and strengthening NARS. Table 3 provides a representative list of types of research and other activities undertaken by the CGIAR and potential outputs under these five program agenda. This is not a comprehensive list of all the outputs of the research efforts of CGIAR, but is meant to give a broad picture of the types of outputs that can result from CGIAR research activities. The outputs range from tangible ones like improved crop varieties, tree species or animal breeds; germplasm collected or conserved; and numbers of people trained; to intangible ones like improved management practices, policy recommendations, development of research methodologies, and contributions to scientific advancement. Since the focus of this study is on the documented impacts, rather than outputs, no attempt is made to survey each center and make a comprehensive list of all their outputs in the context of SSA.

Table 3 also lists the 52 impact studies identified in step 3 of the research-to-impact pathway discussed earlier. As expected, improved crop varieties comprise the category of outputs with the most documented impact studies (34). Nine of these simply document adoption¹², nine assess farm-level impacts, and 16 are fully-fledged impact studies that assess benefits of research at an aggregate level. Other major outputs assessed by the reviewed studies include farm management practices, introduction of control agents, other improved inputs, and soil management practices. The list also includes one study each that assesses post-harvest technology, policy recommendation, and training. None of the studies reviewed document impacts of any outputs under the biodiversity conservation research agenda.

The large number of studies documenting research on the impacts of productivity enhancement corresponds with the level of resources historically devoted to this portion of the research agenda. However, the few impact studies for outputs in other research agenda categories should not necessarily be interpreted as a lack of impact in those categories. This is because there are methodological difficulties in assessing impacts of certain types of research and development activities. The adoption of outputs from research that result in information or ideas may be more difficult to trace than the uptake of technologies. Furthermore, data for trends in non-productivity related benefits are often not readily available, and counterfactual scenarios may be particularly difficult to derive when the benefits of research are in the form of losses avoided.

More than half of the 52 reviewed studies document adoption in terms of numbers of farmers using a given technology over a certain affected production area, or estimate adopter-level impacts (e.g., increased yields, income, employment opportunities, improved nutrition, and gender impacts). Twenty-three studies are classified as impact studies that extrapolate benefits at an aggregate level (province,

¹¹ For example, these include later generation outputs or technologies resulting from NARS research that are not distinctly (or directly) attributable to a partnership with the CGIAR system, even though contributions of such a partnership in early generation research and the overall outputs are acknowledged.

¹² Studies referred to in this paper as ‘documenting adoption’ and classified in Annex A and Table 3 as impact studies under the ‘adoption’ category include analyses that document the extent of adoption of a CGIAR technology/product, but do not present any in-depth analysis of adopter-level or economy-wide benefits.

Table 3. Number of impact studies reviewed by indicators of output under five major CGIAR program agendas

CGIAR program agenda in SSA	CGIAR average expenditures in SSA: 1972–2002 (US\$/year)	Types of research activities	Number of studies tracing impacts up to a given step in the research-to-impact pathway (total reviewed = 50) ^a				
			Indicators of potential outputs	Adoption	Adopter-level estimates	Aggregate benefits beyond individual adopters	Total
Increasing productivity	48 million	Conventional breeding (crops, trees, animal, and fish); biotechnology; on-farm research; participatory research; IPM; animal diseases; vaccine development	Improved seeds	9	9	16	34
			New/improved farm management practices (crop, agroforestry, livestock, and aquaculture)		2	2	4
			Control agents in a farming system to mitigate biotic stresses			4	4
			Other new/improved inputs (fertilizers, machines, vaccines, and feed crops)		1	2	3
			Improved breeds of trees, fish, and animals		1		1
			New/improved post-harvest technologies		1		1
			New/improved post-harvest management practices				
			New/improved management of terrestrial resources (soils, flora, and fauna)		2		2
			New/improved farm management practices (crop, livestock, aquaculture, and agroforestry)		1	2	3
			New/improved plant/tree species in a farming/agroforestry system				
Protecting environment	14 million	Integrated natural resource management; geographic information systems; simulation and modeling; on-farm research; participatory research; agroecosystems mapping	New/improved inputs or farming methods that reduce environmentally harmful practices				
			New/improved management of water resources as an input to agriculture and as a habitat for living aquatic resources		1	2	3
			New/improved management of forest resources				

Biodiversity conservation	7 million	Gene banks; information systems; germplasm exchange	Collection and exchange of germplasm (crops/trees) Conservation of genetic resources (crops/trees) New/improved management practices and farming techniques that promote farm-level biodiversity (e.g., mixed systems and crop rotations) Genetic linkage maps			
Improving policies	9 million	Socioeconomic research; policy analysis; data collection and analysis	Recommendations of policies conducive to technology development and adoption Recommendations of policies for improved NRM management Development of research methodologies			
Strengthening NARS	22 million	Training; collaborative research partnerships; consultation	Research networks (regional) Trained human resources Capacity for policy analysis and development by NARS Capacity to conduct research by NARS			
All reviewed studies				11	17	24
						52

^a Some studies are listed under multiple CGIAR program outputs. Thus, the column totals do not necessarily sum up to the totals in the last row.

country, region, continent, or global). Again, the absence of any aggregate-level impact studies under the categories of research targeted towards biodiversity conservation, improving policies and strengthening NARS is quite typical of the general literature on impact assessment.

Table 4 maps the distribution of the 52 reviewed studies by technologies. More than 70% of the studies deal with CGIAR-mandated food crop sectors in SSA. A couple of studies deal with agroforestry, aquaculture, and livestock farming systems, while some studies are not specific to any sector but deal with outputs of such cross-cutting research themes as fallow systems, no tillage, alley farming, machinery, policy, and training. Again, a higher proportion of studies assess the impacts of crop sector outputs than other outputs.¹³

Since adoption is a necessary condition for research impact, it can be expected that research outputs with wide-scale adoption should present viable cases for impact assessment. Thus, research outputs with high adoption figures but which have not been subjected to impact assessment represent likely gaps in coverage. In the following sub-sections the authors review claims made regarding the adoption of major research outputs of centers in order to set the background for subsequent appraisal of the assessed impacts. Major claims regarding adoption and potential impacts of different outputs of CGIAR–NARS research are discussed below under the broad categories of CGI research and other research (e.g., improvement in farm management practices, post-harvest research, improvement in other inputs, improvement in policies, and NARS strengthening). It is beyond the scope of this study to assess all the methods by which these estimates have been calculated where no impact assessment has been conducted. It is important to note that these figures have not been derived with consistent methods or rigor. Nonetheless, they should give a rough idea of the outputs for which impacts might be substantial and assessable.

Evidence of adoption and potential impacts of research on crop germplasm improvement

Although, not comprehensive across all crops, CGI research is the most documented in terms of adoption and potential impacts among all the outputs of CGIAR. In the late 1990s, estimates of adoption of CGIAR-related improved varieties¹⁴ in a region where they are economically important crops varied from 12% (relative to total crop area) for sorghum (2.4 million ha); 11% for maize in East and southern Africa (1.6 million ha); 15% for beans in East and southern Africa (0.26 million ha); 18% for cassava, continent-wide (1.6 million ha); 24% for maize in West and Central Africa (2 million ha); 25% for rice in West Africa (1 million ha); 41% for potato continent-wide (165,000 ha); and 57% for wheat continent-wide (1.8 million ha) (Table 5). The documented adoption for crops such as millet and groundnut at an aggregate level is less than 1% of the total planted area. Adoption of CGIAR-related improved varieties for other crops (such as cowpea, soybean, and sweet potato) is documented at a state, province, or country level, but not at an aggregate level of a region or the continent.

Table 6 summarizes documented and non-documented adoption claims for the 10 major CGIAR-mandated food crops in SSA – wheat, rice, maize, sorghum, millet, bean, groundnuts, cassava, cowpea, and potato. Based on these adoption claims, the total area in SSA planted to CGIAR-related improved varieties across these 10 major food crops was 11 million ha in the late 1990s.¹⁵ The low levels of documented adoption of

¹³ There are two possible explanations for the distribution (or lack) of impact evidence presented in Tables 3 and 4. One is the lack of methodological ability to assess impacts of these types of outputs, the other is that the distribution reflects a lack of actual impact from outputs of the CGIAR system in sectors such as agroforestry, livestock research, policy, and training. However, no attempt is made in this assessment to gather empirical evidence that either supports or refutes one or both of these possible explanations. Making any credible assessment of the outputs of CGIAR research in SSA is beyond the scope of this assessment, which is focused more on documenting evidence of impacts rather than building an inventory of outputs.

¹⁴ The term CGIAR-related improved varieties is used in this study to refer to varieties that are either: a) CGIAR center × CGIAR center selected, b) CGIAR center × NARS selected, or c) NARS with CGIAR center parent.

Table 4. Number of studies reviewed by technology and research focus

Research focus	Total number of studies reviewed	Number of studies that assess a given technology									
		Improved varieties	Improved farm management practices	Improved animal breeds	IPM	Improvement of other inputs	Improved post-harvest technology	Integrated natural resource management	Improved policies	Trained human resources	
Beans	4	4									
Cassava	6	3		2		1					
Cowpea	2	2					1				
Groundnut	1	1									
Maize	4	4									
Potato	4	4									
Rice	3	3									
Sorghum/millet	8	8									
Soybean	1	1									
Sweet potato	1	1									
Wheat	4	4									
Mango	1				1						
Agroforestry	2		1					1			
Aquaculture/fishing	2		1		1				1		
Livestock	2			1				2			
Cross-cutting themes											
Alley farming	1		1							1	
Fallow	2		1							1	
No till	1		1								
Machinery	1				1						
Policy research	1									1	
Training activity	1										1
Total	52										

Table 5. Evidence of impacts of CGIAR investments in research in crop germplasm improvement in sub-Saharan Africa

Evidence of some impact indicators for a given geographic region						
Crop	Major observation ^a	Geographic coverage and time period	Adoption of CGIAR-related varieties at country level			Other benefits
			Planted area (percentage)	Area (ha)	Farm-level impacts (yield gains)	
Beans	Well-documented evidence of impacts at community, country and continent level (mostly East/southern Africa). Community and country-level studies mainly focus on impacts of specific varieties. Only continent-wide estimates aggregate benefits as a value of increased production due to adoption of improved bean varieties and share of CIAT germplasm	East and southern Africa, 1998	1–48% weighted average: 15%	260,000	0.2–0.9 t/ha	Estimated Not estimated
Cassava	Well-documented evidence of impacts for Nigeria and continent-wide. Studies on Nigeria mainly focus on impacts of improved cassava varieties at community level. Only, continent-wide estimates aggregate benefits as value of increased production due to adoption of improved cassava varieties and share of CGIAR germplasm	SSA, 1998	2–34% weighted average: 18%	1,600,000	1–125% at a country level; 49% weighted average	Estimated Distributonal impacts between producers (28%) and consumers (72%) as a percentage share of total surplus estimated for Nigeria
Cowpea	Scarce evidence. Only evidence of documented impacts at a community level in Nigeria for one IITA-developed variety. No evidence of aggregate-level impacts	Kano state, Nigeria, 1997	1500 farmers	Not estimated	Not estimated	Not estimated Increased fodder
Groundnut	Well-documented evidence of adoption and impacts at country level of specific varieties across nine countries in East/southern Africa. No evidence of aggregate-level impacts	Southern Africa, 1999	0.2–15% of planted area at a country level	Not estimated	5–50% for specific varieties at a country level	Not estimated Not estimated
Maize	Well-documented evidence of impacts for West/Central Africa. Well-documented evidence of adoption in East/southern Africa. No evidence of aggregate-level impacts	West and Central Africa, 1998	1.3–89% weighted average: 24%	2,000,000	17–100% at a country level; 45% weighted average	Estimated Increased food security
		East and southern Africa, 1998	11%	1,600,000	15% (conservative estimate)	Estimated No estimated

Millet	Case studies of adoption and impacts of specific varieties at country level. No evidence of aggregate-level impacts	Southern Africa, 1995–97	14–49% of planted area at a country level	180,000	Not estimated	Not estimated	Not estimated
Potato	Evidence of impacts documented for selected varieties in some countries. Documentation of adoption for SSA. No evidence of aggregate-level impacts	SSA, 1990s Zaire–Nile divide in Burundi, Rwanda, Uganda and Zaire, 1993	40% of planted area 50%	165,500 55,000	Not estimated 2.8 t/ha	Not estimated Estimated	Not estimated Not estimated
Rice	Case studies document adoption and impacts in a few countries in West Africa. Documentation of aggregate-level impact	West Africa, 1998	40%	1,000,000	24% productivity gains in some countries	Estimated	Not estimated
Sorghum	Case studies of adoption and impacts of specific varieties at country level	SSA, 1990s	3–36% of planted area at a country level weighted average: 12%	2,400,000	1–125% at case study region level	Not estimated at a regional level	Not estimated
Soybean	Lack of comprehensive evidence of aggregate-level impacts; only one case study documents evidence of adoption and impacts in one region in Nigeria	Benue State, Nigeria, 1997	30%	Not estimated	Not estimated	Not estimated	Impact on household income generation and distribution, human capital development, gender relations, social equity, and nutrition
Sweet potato	Lack of comprehensive evidence of aggregate-level impacts; only one case study documents evidence of adoption and impacts in one region in Kenya	Kenya, 2001	Not estimated	Adoption estimated as 60–70% farmers. Data on adoption area not available	56–103% in the study area	Not estimated	Nutritional impacts
Wheat	Well-documented evidence of adoption for East/southern Africa. Well-documented evidence of global impacts (with SSA included as one of the regions)	SSA, 1997	57%	1,800,000	0.2 t/ha	Estimated	Not estimated

^a For an explanation of Acronyms see acronym list, page viii

Source: See studies listed in Annex B for respective crops.

Table 6. Adoption of improved varieties of major food crops in sub-Saharan Africa, late 1990s

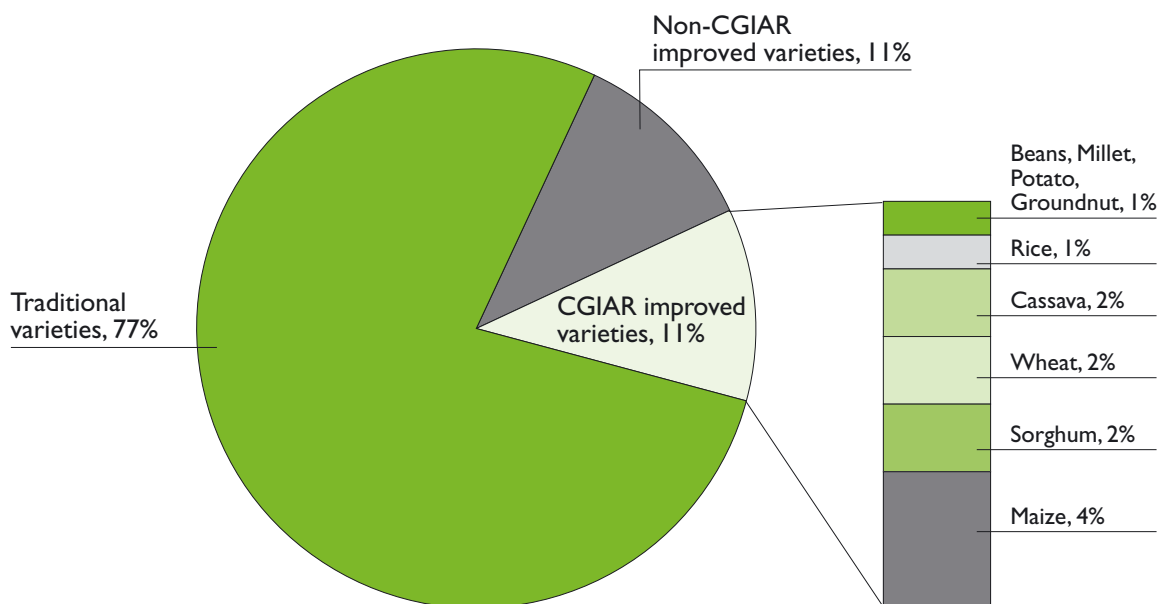
Crop	Source	Total area planted in late 1990s (ha) ^a	Adoption claims documented in the literature (late 1990s)			
			Area planted to improved varieties	Area planted to CGIAR-related improved varieties ^b	Area planted to improved varieties as percentage of total area planted	Area planted to CGIAR-related varieties as percentage of total area planted
Maize	Morris et al. (2003); Manyong et al. (2003)	23,088,400	10,847,331	3,649,000	47	16
Sorghum	Deb and Bantilan (2003)	20,450,402	3,381,944	2,399,043	17	12
Millet	Bantilan and Deb (2003)	19,321,004	411,906	180,298	2	1
Groundnut	Bantilan et al. (2003)	9,583,899	456,079	42,884	5	0.45
Cowpea	None found	9,116,123	–	–	–	–
Cassava	Johnson et al. (2003b)	9,018,400	1,897,078	1,623,312	21	18
Rice	Dalton and Guei (2003)	4,084,000	2,589,187	1,027,908	63	25
Wheat	Heisey et al. (2002)	3,288,170	2,170,192	1,874,257	66	57
Bean	Johnson et al. (2003a)	1,738,000	401,262	260,700	23	15
Potato	Walker et al. (2003)	407,769	258,933	165,554	64	41
All 10 crops		100,096,167	22,413,913	11,222,956	22	11

^a As reported in the source or FAOSTAT (Food and Agriculture Organization of the United Nations online statistical database).

^b CGIAR-related varieties include the following general categories: 1) CGIAR center x CGIAR center selected; 2) CGIAR center x NARS selected; and 3) NARS x CGIAR center parent.

improved varieties for millet and groundnut, and the absence of any documented adoption for cowpea are striking: these three crops together cover close to 40 million ha of planted area in SSA but the documented adoption of CGIAR-related varieties for these three crops is just over 220,000 ha. Thus, even though the documented adoption for food crops such as wheat and potato is more than 40%, the overall estimated adoption of CGIAR-related varieties across these 10 crops is only 11% of the total planted area. This is about 50% of the area documented for all improved varieties in SSA (Figure 7).

Figure 7. Share of CGIAR-related improved varieties and other sources of varieties in the total area planted to major food crops in sub-Saharan Africa, late 1990s



The yield effects documented are quite variable across crops, making it difficult to make any blanket assessment about this impact indicator across all crops. Evenson (2003) estimates CGIAR contributions to yield growth due to CGI research in SSA to be in the range of 0.11–0.13% per year. This range is much smaller than the 0.30–0.33% per year average yield growth across all developing regions (Evenson, 2003). These estimates suggest that despite substantial introduction of new improved varieties of different crops in SSA, there has not been a great aggregate impact on yields, compared with other regions. The often-cited reason for this low aggregate impact of CGI technology is low adoption. It is compounded by low soil fertility, failure to incorporate smallholder preferences adequately, insufficient supporting infrastructure (such as seed systems), non-availability of other inputs like fertilizer, lack of information, and inappropriate policies (Byerlee and Heisey, 1996; Ahmed et al., 2000; Doss et al., 2003).

Evidence of aggregate economic benefits as a result of CGIAR-related improved varieties in SSA is less extensive and comprehensive than evidence of adoption. Nonetheless, several studies do estimate economic benefits as the value of increased production due to the adoption and yield gains of CGIAR-related improved varieties. These documented estimates are the subject of the critical review process outlined in step 4 and are discussed in the context of the meta-analysis in the next section.

¹⁵ As a comparison, areas planted to CGIAR-related improved varieties in other regions (Evenson, 2003) are estimated as follows: 55% (Asia), 30% (Latin America), and 48% (Middle East–North Africa).

Other benefits of improved varieties documented in the reviewed assessments include impacts on household food security, nutrition, and gender relations. For some crops, such as cowpea, the impact in the form of increased by-products like fodder is also important. Some studies document the distributional impacts of improved varieties between consumers and producers. A study of cassava by Falusi and Afolami (1999), reports the share in total benefits by producers to be 28% and by consumers to be 72%. This result concurs with the general literature on distributional impacts of agricultural research. Interestingly however, this study shows that the share of producers' benefits in technology surplus declines as more output is sold. That means a technological innovation has more positive distributional impact on producers in semi-subsistence agriculture (characteristic of much of SSA) than in commercialized agriculture.

Although improved varieties have other benefits, none of the reviewed studies measure or estimate these benefits. An analysis by Evenson and Rosegrant (2003) is the only one that tries to estimate the effects of CGIAR research into CGI on total area, food production, and food consumption, in different regions of the world. Their analysis shows that in the absence of the global CGIAR research contributions to CGI, the area planted to major food crops in SSA would have been 0.6–1.0% more than the actual cropped area in the late 1990s. The effect on total food production in SSA would have been a reduction by 1–2%. Additionally, the number of malnourished children would have increased by 1% and the availability of calories to the general population would have declined by 3–4%. These estimated effects in SSA are more modest than many would expect.¹⁶ They are also lower than the effects estimated for other regions of the developing world (Evenson and Rosegrant, 2003).¹⁷ This is because low CGIAR-related crop genetic gains (0.11–0.13% per year in SSA) are less than one-third those of other regions. SSA also has a lower adoption rate of CGIAR-related improved varieties than other developing regions.^{18, 19}

Evidence of adoption and potential impacts of research other than crop germplasm improvement

Evidence of adoption and impacts is available for the following technologies: biological control; farm management practices such as no till, alley farming, fallow trees, and integrated aquaculture; improved livestock; introducing new or improved inputs; post-harvest technology; and policy research and training (Table 7). These technologies contribute to the CGIAR program agenda of increasing productivity, protecting environment, improving policies, and strengthening NARS.

IITA research into biological control in cassava (Zeddies et al., 2001; Coulibaly et al., 2004), and research by ILRI on the impact of fodder bank technology (Elbasha et al., 1999) are the only documented examples we found of wide-scale adoption of CGIAR research other than research relating to the uptake of improved varieties. These studies document the spread of very specific research outputs across several countries in the region. Other impact assessment studies reviewed cover a relatively small geographic area (e.g., state, province, or region within a country), with the adoption of technologies ranging from a few hundred to a few thousand farmers and hectares (Table 7). These are quite insignificant levels of adoption compared with the estimates of wide-scale adoption documented for improved varieties presented in Tables 5 and 6.

As with improved varieties, the impacts of most of the technologies listed in Table 7 are evident either in increased farm-level yields or reduced costs (both indicating increased productivity), which result in

¹⁶ It is important to note, however, that the implications of area, production, and food consumption effects even in the 1–3% range are significant from an environmental, health, and economic welfare perspective for millions of people on the continent.

¹⁷ The comparative estimates for the area effect in other regions are: 1.5–3.1% (Latin America); 1.8–2.1% (Middle East–North Africa); and 1.5–1.7% (Asia). Similarly, the estimates for production effects in other regions are: 5.4–5.6% (Latin America); 7.4–7.9% (Middle East–North Africa), and 8.3–9.1% (Asia). The average effect on food consumption and calorie availability across all developing countries is estimated to be in the range of 2.0–2.2% and 4.5–5.0%, respectively.

¹⁸ See footnote 15 for comparative estimates of adoption in other regions.

¹⁹ The rate and levels of investments in agricultural research and development by CGIAR and NARS in SSA over the past three decades has been lower than in Asia and Latin America. Hence, with the long lag times, it may be premature to make such comparisons.

Table 7. Evidence of impacts of CGIAR research on technologies or outputs other than improved varieties

Evidence of some impact indicators for a given technology and geographic region							
Technology	Major observation	Geographic coverage (study/technology)	Adoption	Adopter-level impacts	Aggregate economic benefits	Other benefits/impacts	Involved CGIAR center ^a
Biological control	Well-documented evidence of impacts at country level (mostly in West Africa) and continent level. Aggregate benefits estimated as value of prevented production/ revenue loss due to the release of biological control agents	SSA, 1980s and 1990s (biological control of cassava mealybug, cassava green mite, mango mealybug, and water hyacinth)	Benin (4 documented impacts), Ghana, Nigeria (2 documented impacts), and another 24 countries (1 documented impact) for cassava mealybug biological control	Production and/or revenue loss prevented	Estimated	Better water quality and human health	IITA
Improved farm management practices	Lack of comprehensive evidence of aggregate level impact. A few case studies document adoption and impacts of farm management practices at a project or country level	Ghana, 2002 (no-till) Malawi, 2005 (IAA)	100,000 farmers (45,000 ha) 50% of over 5,000 fish farmers	45% yield gain Increased production of fish	Not estimated Estimated	Improved soil fertility, labor saved Distribution impacts, food security and health, sustainability, and capacity building	CIMMYT WorldFish
Improved livestock	Lack of evidence of impacts. Only one case study of adoption study documenting adopter-level impacts based on a sample of 202 farmers in one province in Kenya	Cameroon, Benin, Nigeria, 1996 (alley farming)	Percentage of farmers: 24% (Cameroon), 32% (Benin), and 64% (Nigeria)	Financial gain (reduced cost of fertilizer due to soil fertility improvement)	Not estimated	Production of staking materials and poles, fuelwood, and erosion control	IITA, ILRI, and ICRAF
		Western Kenya, 2001 (improved fallow)	22% of sampled farmers	Increased yields of crops following fallow (due to improved soil fertility)	Not estimated	Increased soil organic matter, improved color of soil, and elimination of serious weed	ICRAF
		Zambia, 2005 (fertilizer tree fallow system)	47,000 farmers in 2000–2002	Increased yields of crops following fallow (due to improved soil fertility) and value of nitrogen fixation	Estimated	Reduced risk of drought and fuelwood	ICRAF

Table 7. Evidence of impacts of CGIAR research on technologies or outputs other than improved varieties (continued)

Technology	Evidence of some impact indicators for a given technology and geographic region					Involved CGIAR center ^a
	Major observation	Geographic coverage (study/technology)	Adoption	Adopter-level impacts	Aggregate economic benefits	
Improvement of other inputs	Lack of extensive evidence of impacts. Documented impacts based on introduction of forage crops and vaccines in a livestock system and a mechanical innovation (plough) in Ethiopia	SSA (impact of fodder banks), 1997 Kenya (<i>Calliandra calothyrsus</i> as a fodder shrub) Ethiopia (broadbed-maker plough)	27,000 farmers in 15 countries (19,000 ha) About 48,000 farmers by 2005 1,080 farmers in 1998 (2% of farmers using improved wheat or 625 ha)	Increased meat and milk production Reduced costs by US\$130 per cow per year Labor saving and increased yields	Estimated Not estimated Estimated	ILRI ICRAF ILRI
Improved post-harvest technology	Lack of evidence of impacts. Only one case study of adoption documenting adopter-level impacts based on a survey of 139 producers in one province in Nigeria	South-western Nigeria (Cassava flour technology)	42 producers and users surveyed	Labor saving and higher income	Not estimated	IITA
Policy research	Lack of evidence of impacts. Only one case study documenting impacts of policy research and capacity building efforts in one country	Malawi, 1999	Government of Malawi (interventions addressing malnutrition as a result of the availability of food security and nutrition- monitoring data)	Informed decision/ policy making and aversion of social and political costs	Not estimated	IFPRI
Training	Lack of evidence of impacts. Only one case study documenting impacts based on survey responses from 60 beneficiaries	Kenya and Ethiopia	307 graduate students	Increased income, job promotion, and skills/ knowledge acquired	Not estimated	ILRI

^a For an explanation of acronyms see Acronym list, page viii.

Source: *Studies listed in Annex B for respective technology and region.*

increased incomes for adopters. Other potential benefits of some of these technologies include improved water quality, soil fertility, human health, and capacity building. However, none of the reviewed studies measure or estimate these other impacts. The aggregated economic benefits of adopting these technologies are estimated by five of the ten studies reported in Table 6. These are discussed in the following section.

Evidence of adoption and impacts of policy research and training is scarce. One reviewed study assesses policy research influences, and one other assesses benefits from training activities. It is therefore difficult to derive any conclusions about the impacts of the two program agenda activities ‘improving policies’ and ‘strengthening NARS’ based on just two studies. Clearly, there is a need for additional impact assessment of research in these areas.

The summary of evidence in Tables 5–7 provides an overview of the scale of adoption, the scope, and the size of the potential impacts of CGIAR research in SSA. The data provided by these impact studies must be analyzed to provide a better understanding of the impacts of agricultural research in SSA by CGIAR and NARS. However, individual impact studies not only differ in the types of research outcomes being evaluated but also in their methodologies. In this context, and taking the estimate of economic benefits as an example, it is important to determine the certainty with which the estimates of individual studies can be aggregated in order to derive estimates of total benefits attributable to the CGIAR. Similarly, it is important to assess the total costs incurred by NARS and other partners in realizing those benefits. To this end, each study shown in Tables 5–7 that estimates economic benefits is subjected to a critical review process to evaluate the confidence that can be placed in the reported estimates of benefits and costs. The methodology of this process, and the results of the benefit–cost meta-analysis are discussed in the following section.

4. Meta-Analysis of Benefits and Costs of CGIAR–NARS Research in Sub-Saharan Africa

Meta-analysis is the statistical treatment of research results to identify more generalized patterns from case observations. Traditional meta-analysis attempts to draw inferences from as broad a pool of cases as possible, under the assumption that a sufficient population of cases will balance out individual methodological flaws. However, if a meta-analysis consists of the aggregative treatment of results, or if certain methodological flaws are pervasive, this assumption may not be appropriate. In such cases, it is necessary to conduct a ‘best evidence’ meta-analysis, in which methods are scrutinized before results are accepted as part of the analysis (Slavin, 1995). The present study applies this approach.

The meta-analysis considers how the documented benefits of CGIAR–NARS research compare with the associated investment by the CGIAR–NARS partnerships in the region.²⁰ The basic objective is to derive a set of plausible and highly credible aggregate estimates of the benefits accruing from CGIAR innovations in SSA, and to set these against the value of the entire CGIAR–NARS expenditures.

The 24 studies identified in Annex B as *ex post* impact studies assessing aggregate-level benefits of CGIAR–NARS research were the initial focus of this meta-analysis. Studies that assess individual farm-level impacts and/or only estimate the adoption of CGIAR research outputs were excluded (i.e. 28 of the 52 reviewed impact studies) since they do not provide a benefit value for aggregation in the numerator of the BCR. This pool of studies was produced independently by different authors on behalf of various agencies. As a result, there is considerable heterogeneity in the methods and quality of individual impact assessments. Moreover, the aggregated estimates reported in these studies are derived from the extrapolation of location-specific studies. In order to aggregate and compare benefits across these different studies and research areas, some screening of rigor is necessary to ensure that only credible estimates are included. The authors were able to obtain data for all but one study (Falusi and Afolami, 1999). Thus, only 23 studies were finally subjected to the critical review process.

Assessment of credibility

To determine the credibility of individual impact findings, the present study adopts the review framework first proposed by Raitzer (2003) and refined in Raitzer and Lindner (2005). Since no prior set of standards had been identified for an *ex post* impact assessment of research, this framework was developed through a selective review of the literature. The framework is essentially based on two interdependent principles: 1) transparency and 2) analytical rigor.

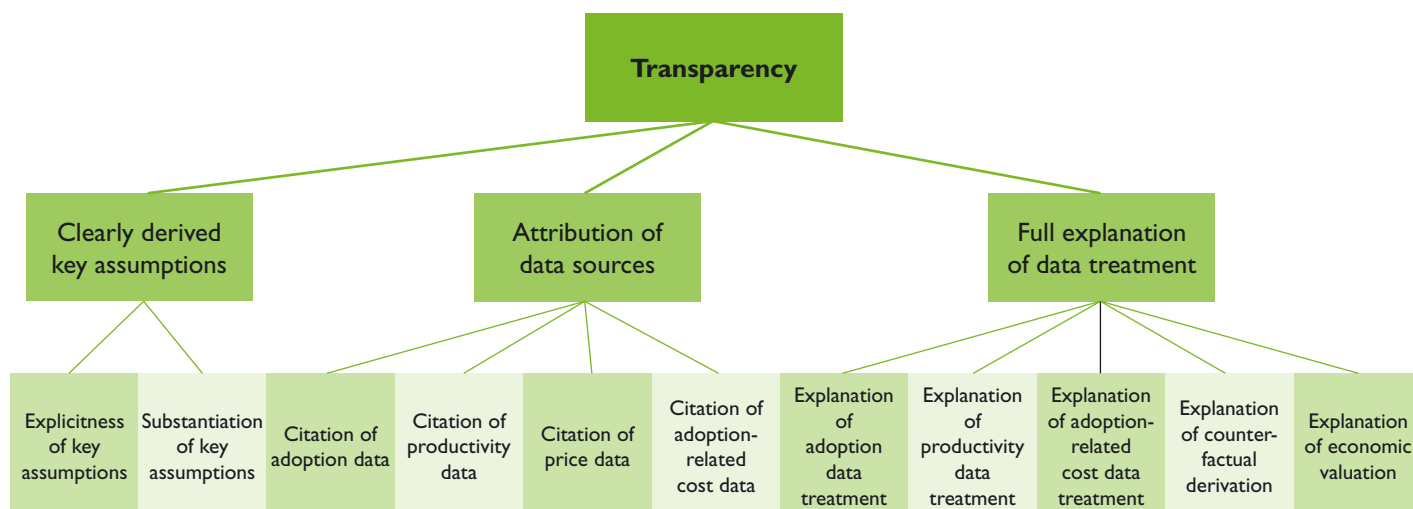
Transparency: criteria and indicators

It is imperative that research is characterized by transparency, since this is necessary for understanding any results produced (Baur et al., 2001). In this study, transparency was represented by three broad criteria (Figure 8):

- Clearly derived and explained key assumptions
- Comprehensive description of data sources
- Full explanation of data treatment

²⁰ The NARS component included in this analysis represents a partial portfolio of the whole system in SSA. It refers to supplementary costs or investments by NARS and other partners incurred towards the development and dissemination of technologies attributed to CGIAR centers. It should not be interpreted as total NARS costs in SSA.

Figure 8. Hierarchical relationship of principles, criteria, and indicators for assessing the transparency of reviewed studies



Clearly derived key assumptions. Two qualitatively assessed indicators – explicitness of key assumptions and substantiation of key assumptions – represented the clearly derived key assumptions.

Comprehensive description of data sources. Any economic analysis can only be as robust as the data it uses, and as a result, the sources for such data should be clearly presented. For this criterion therefore, four indicators were enumerated to describe the comprehensiveness of data sources: description of data sources for extent of adoption (when relevant); productivity effects; costs associated with adoption; and prices for valuing productivity changes.

Full explanation of data treatment. For an analysis to be transparent, the methods applied to calculate benefit estimates from collected data should be described in detail. Explanations of how estimates for adoption levels, productivity effects, adoption-related costs, and economic valuation were inferred from available data were used to give a full explanation of the data treatment. These indicators also represented the clarity with which counterfactual construction and economic valuations were described.

Analytical rigor: criteria and indicators

To date, no framework has been defined in the literature for the appraisal of an *ex post* impact assessment’s rigor. However, as previously noted, a number of methodological publications have been produced to provide guidance to impact assessment of research, and a number of papers have been written concerning common flaws in past approaches. It is possible to infer from these sources the necessary elements for best-practice assessment.

The objective of an *ex post* impact assessment is to attribute the effects of a particular research-derived intervention on the areas of interest, relative to other potential causal factors. This requires the construction of a counterfactual (Baker, 2000). This counterfactual should take into account the relative role of alternative causes in observed changes, and factors that may mitigate the effectiveness of the assessed output in the field.

To address the degree to which the reviewed studies demonstrated causality, three criteria were identified (Figure 9):

- Utilization of a representative data set
- Appropriate data treatment
- Development of a plausible counterfactual scenario.

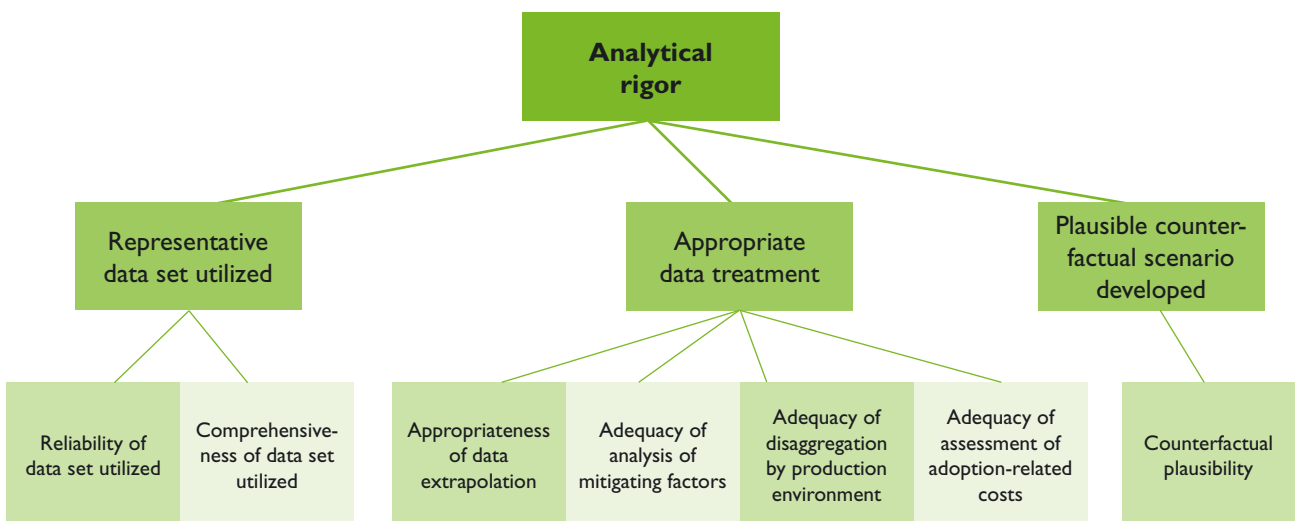
Utilization of a representative data set. For impact to be rigorously demonstrated through *ex post* impact assessment, both the measurement of metrics of interest and the construction of the counterfactual must be rigorous. Measurement and monitoring of metrics of interest requires sufficient data at the scale at which trends will be extrapolated (Maredia et al., 2000). Such data typically include estimates of the spatial area at which an innovation or new technology is applied or adopted, as well as information regarding the changes in inputs or outputs related to the innovation’s adoption. Prices for the shifted production or saved inputs are also required. In the current study, utilization of the representative data set was represented by two indicators: reliability and comprehensiveness of the data set utilized.

Appropriate data treatment. To rigorously estimate research impacts, it is essential that robust methods are used. The extrapolation from available data of trends on adoption and productivity in an appropriate and representative manner is an important element of this process. Mitigating factors that may prevent expected patterns of benefits from being realized need to be assessed. Four indicators were used for evaluating the fulfillment of appropriate data treatment: appropriateness of data extrapolation; adequacy of analysis of mitigating factors; adequacy of disaggregation by production environment; and adequacy of assessment of adoption-related costs.

Development of a plausible counterfactual scenario. In the absence of a particular research program, it is likely that some technological advancement will take place. For an impact assessment to be accurate, this must be captured in the counterfactual scenario, which must be credible (Baur et al., 2001; Salter and Martin, 2001). The plausibility of implicit or explicit counterfactuals indicates the degree to which the assumed course of events, in the absence of the innovation, represents a realistic next-best course of action.

Rating of studies against the review framework. The 23 impact assessments in the study pool were reviewed against the framework developed using the above criteria, and a numerical score of zero to three was assigned for each indicator (Table 8). A score of zero indicates that the indicator is unfulfilled

Figure 9. Hierarchical relationship of principles, criteria, and indicators for assessing the analytical rigor of reviewed studies



Source: Adapted from Raitzer (2003)

Table 8. Principles, criteria, indicators and rating examples for evaluating benefit–cost studies

Principle	Criteria	Indicator	Low rating (0)	High rating (3)
TRANSPARENCY	1. Clearly derived key assumptions	Explicitness of key assumptions	Major assumptions underlying analysis are not defined	All major assumptions explicitly stated
		Substantiation of key assumptions	Unclear basis for explicit assumptions	Explicit assumptions have logical justification and/or citation
	2. Comprehensive attribution of data sources	Citation of adoption data	Unclear basis of adoption estimates	Adoption estimates cited and/or data collection described
		Citation of productivity data	Unclear basis for productivity claims	Productivity claims based on cited references or clear methods
		Citation of adoption-related costs data	Unclear empirical basis for deriving costs of adoption	Estimates of adoption-related costs cited or given logical justification
		Citation of price sources	Unexplained basis of commodity prices	Cited basis for commodity prices
	3. Full explanation of data treatment	Explanation of scaling up adoption estimates	No basis provided for adoption estimates	Gathering process for adoption estimates defined
		Explanation of scaling up productivity estimates	Unclear extrapolation from limited productivity impact data	Clear methodology for scaling-up estimates from specific sites
		Explanation of scaling up adoption-related costs	Incorporation of costs associated with adoption unclear	Costs considered (or not considered) in an explicit manner
		Explanation of economic valuation	Commodity prices used, discounting and deflating unclear	Commodity prices used, discounting and deflating clearly presented
		Explanation of counterfactual derivation (explicitness)	No 'without' scenario	Comprehensive development of a 'without' scenario
	ANALYTICAL RIGOR	1. Utilization of a representative data set	Reliability of data set utilized	Data sourced from uncorroborated expert opinion or assumption
Comprehensiveness of data set utilized			Data sourced from single location or trial	Large number of sample sites representing range of relevant conditions
2. Appropriate data treatment		Appropriateness of data extrapolation	Limited data or assumptions extrapolated over large spatial/temporal scales	Data only extrapolated over populations represented
		Adequacy of analysis of mitigating factors	No mitigating factors considered	Consideration of major relevant alternative causal factors
		Adequacy of capturing variability in the target environment or population	Only 'average' conditions considered	Heterogeneity in impacts appropriately captured
		Adequacy of disaggregation of benefits/surpluses by consumer/producer groups	Gross benefits presented without analysis of surplus recipients	Impacts disaggregated among different producer and consumer groups
3. Development of plausible counterfactual scenario		Counterfactual plausibility	Counterfactual represents unrealistic, overly cynical course of action	Counterfactual represents realistic, likely and substantiated path of events
4. Plausible institutional attribution		Plausibility of institutional attribution	No attribution attempted	Empirically based attribution derived through counterfactual

or unconsidered, whereas a score between one and three shows partial to complete fulfillment of the indicator. Each indicator was weighted equally and the ratings aggregated and averaged to derive a rating for transparency and for analytical rigor. The results of the application of the above criteria to the 23 impact assessments are reported in Annex D.²¹

Scenarios of the aggregation of research benefits

Three basic scenarios of aggregate research benefits of the 23 selected studies are constructed for the meta-analysis based on the average scores for the principles of transparency and analytical rigor: potential, plausible, and substantially demonstrated benefits. The number of studies in each of these scenarios is shown in Table 9. These scenarios are progressively exclusive as criteria become more restrictive. Thus, the ‘potential’ benefits scenario is inclusive of all ‘plausible’ benefits, which in turn is inclusive of all ‘substantially demonstrated’ benefits. Each of these scenarios is split into two sub-scenarios – *ex post* and *ex post + ex ante*.

Table 9. Number of studies included in the three scenarios of the meta-analysis

	Scenario 1 ‘Potential’ benefits	Scenario 2 ‘Plausible’ benefits	Scenario 3 ‘Substantially demonstrated’ benefits
Number of studies	23	19	9
Criteria	All-inclusive	Studies with an average score of more than 1.5 for transparency and more than 1.0 for analytical rigor	Studies with an average score of more than 1.5 for both transparency and analytical rigor

Scenario 1: ‘Potential’ benefits

This scenario includes aggregated benefits of all the 23 impact studies in the study pool. Some of the included benefit estimates have been based on very limited empirical data and there is little certainty that all of the included benefits have been realized. Nevertheless, this scenario does help to illustrate the level of benefits of CGIAR–NARS research in SSA that has been documented in the literature.

Scenario 2: ‘Plausible’ benefits

The 19 studies included in this scenario received moderate ratings for transparency (an average score of at least 1.5, based on the 0–3 scale). In addition, studies in this scenario demonstrated at least limited levels of rigor, with average scores of 1.0 or greater for the indicators of analytical rigor.

Scenario 3: ‘Substantially demonstrated’ benefits

This scenario is a subset of the ‘plausible’ benefits scenario and includes only those benefits that have been rigorously assessed (nine studies). The additional criterion applied for inclusion in this scenario is a higher rating for analytical – an average score of at least 1.5. This is to calculate a high-confidence lower bound measurement of economic impacts attributable to CGIAR and NARS activities in SSA.

²¹ These scores are based on the authors’ subjective judgment and evaluation of the studies’ data and analyses. They are based on what is actually stated in the documentation of the studies reviewed. There is no verification of the accuracy of the methodologies used nor of the quality of fieldwork. The evaluation framework was only applied to the economic impact assessment component of a study. Thus, scores do not reflect the rigor of the overall study, which in some cases had a much broader focus than economic impact assessment.

Ex post and ex post + ex ante sub-scenarios

Since this work focuses on *ex post* impact research, all the studies included in the study pool include benefit estimates based on empirical evidence of adoption and adopter-level impacts for at least one year. However, the time period of the documented benefits reported varies across the 23 studies (Table 10) and can be grouped accordingly: a) 10 studies report *ex post* multi-year benefits up to the year of the respective study analysis or up to 2004 (e.g., Byerlee and Traxler, 1995; Elbasha et al., 1999; Rohrbach et al., 1999); b) six studies report *ex post* benefits for a single year (e.g., Dalton and Guei, 2003; Lantican et al., 2005; Manyong et al., 2003; Morris et al., 2003); c) the remaining seven studies include both an *ex post* and *ex ante* analysis of projected benefits beyond 2004 (e.g., Yapi et al. (1999) and Zeddies et al. (2001) provide estimates of costs and benefits covering the period 1982–2018 and 1979–2013, respectively). In such studies, the projected costs and benefits beyond the year of *ex post* impacts are substantiated by assumptions about the projected trends of important impact variables. They are also justified based on the widely used assumption that benefits from research are cumulative and continue to occur beyond the period of analysis (Evenson, 2001).²²

Ex post sub-scenario

This scenario is an ultra-conservative approach that includes estimates of benefits documented by a study up to 2004 (the time period of estimated costs included in the meta-analysis). Thus, if a study has reported benefit streams continuing beyond 2004, these projections are not included in the base scenario. This excluded seven of the original 23 studies. The rationale for truncating the benefit streams to the year 2004 for these seven studies is to maintain a more conservative *ex post* scenario so that the total benefits included in the benefit–cost meta-analysis are only those that have been documented as realized up to 2004.²³

Ex post + ex ante sub-scenario

For 10 studies, the reported benefits for the entire documented time period are included (e.g., 1982–2018 for Yapi et al., 1999); no attempt being made to truncate the benefits stream.²⁴ The other studies included in the meta-analysis provide *ex post* estimates of benefits for only a single year. It is extremely conservative to assume that benefits of past research are realized for only one year. Hence, to reflect the realistic assumption of continued benefits of past research beyond a single year, such estimates of single-year benefits are projected to continue for 10 years beyond the reported year (in nominal values, prior to discounting). The projections of single-year benefits to 10 further years are applied to six studies, all of which deal with CGI research (shown in Table 10). While this second sub-scenario helps to offer a more realistic estimate of benefits for past research investments, the results are still speculative, as research products that are not assessed by the impact study or not yet realized are implicitly included.

Since the cost data included in the meta-analysis are up to 2004, the estimated BCRs reported for the two sub-scenarios are conservative. This is due to the fact that, in the final years, the benefits from innovations to be generated in future are not included in the numerator (as they are not yet documented). Thus, the reported BCRs are indeed lower-bound estimates of indicators of impacts of CGIAR–NARS investments in SSA for the period 1966–2004.

²² Alston et al. (2000) also report and analyze documented internal rates of return of several studies that are based on both the documented *ex post* and the projected *ex ante* benefits.

²³ This scenario does, however, include *ex ante* estimates of benefits for some studies up to 2004.

²⁴ In a few studies where costs are also projected to continue beyond 2004 (i.e. the last year for which CGIAR cost data is available), the benefits included were net of projected costs.

Table 10. Studies and time period of estimates of benefits included in the three scenarios and two sub-scenarios of the meta-analysis

Study number	Study	Benefits included in a given meta-analysis scenario				Time period of benefits analysis (as reported)		Time period of benefits included in two sub-scenarios	
		Potential	Plausible	Substantially demonstrated	Ex post (as reported)	Ex ante (as reported or projected)	Ex post (as reported up to 2004)	Ex post + Ex ante (as reported or projected)	
3	Ahmed et al. (1994)	X	X	X	1984–1991	1984–1991	1984–1991	1984–1991	
4	Ajayi et al. (2005)	X			2004–2008	2004	2004–2008	2004–2008	
6	Anandajayasekaram et al. (1995)	X	X		1988–1999	1988–1999	1988–1999	1988–1999	
9	Bokonon-Ganta et al. (2002)	X	X	X	1992–2009	1992–2004	1992–2004	1992–2009	
10	Byerlee and Traxler (1995)	X	X	X	1978–1990	1978–1990	1978–1990	1978–1990	
11	Coulibaly et al. (2004)	X			1993–2000	1993–2000	1993–2000	1993–2000	
12	Dalton and Guei (2003)	X	X		1998	1998	1998	1998–2007 ^b	
14	de Groote et al. (2003)	X	X		1999–2019	1999–2004	1999–2004	1999–2019	
17	Dey et al. (2005)	X			1996–2018	1996–2004	1996–2004	1996–2018	
19	Elbasha et al. (1999)	X	X	X	1979–1997	1979–1997	1979–1997	1979–1997	
21	Fall (2005)	X	X		1990–2000	1990–2000 ^a	1990–2000 ^a	1990–2000 ^a	
26	Heisey et al. (2002)	X	X		1997	1997	1997	1997–2001 ^b	
28	Johnson et al. (2003a)	X	X		1979–1998	1979–1998	1979–1998	1979–1998	
29	Johnson et al. (2003b)	X			1998	1998	1998	1998–2007 ^b	
32	Lantican et al. (2005)	X	X		2002	2002	2002	2002–2011 ^b	
33	Manyong et al. (2003)	X	X		1998	1998	1998	1998–2007 ^b	
36	Morris et al. (2003)	X	X		1998	1998	1998	1998–2007 ^b	
42	Rohrbach et al. (1999)	X	X	X	1992–1996	1992–1996	1992–1996	1992–1996	
43	Rueda et al. (1996)	X	X	X	1981–1993	1981–1993	1981–1993	1981–1993	
44	Rutherford et al. (2001)	X	X	X	1994–1999	1994–1999	1994–1999	1994–1999	
49	Tre J.P. (1995)	X	X		1984–2010	1984–2004 ^a	1984–2004 ^a	1984–1997 ^a	
51	Yapi et al. (1999)	X	X	X	1986–2018	1986–2004	1986–2004	1986–2018	
52	Zeddies et al. (2001)	X	X	X	1982–2013	1982–2004	1982–2004	1982–2013	

^a Excluding the year 1998 under the ex post scenario and 1998 and beyond, under the ex post + ex ante scenario. For these excluded years, the more comprehensive regional estimates by Dalton and Guei (2003) were used instead.

^b Studies to which the projections of single-year benefits for 10 further years are applied.

Aggregation of costs and benefits: methodology

Estimating the share of sub-Saharan African benefits in global estimates

Four studies (Byerlee and Traxler, 1995; Heisey et al., 2002; Morris et al., 2003; and Lantican et al., 2005) out of the 23 in the meta-analysis report benefits to SSA as part of the global estimated benefits from CGIAR–NARS research. The reported global benefits are adjusted to ensure that only benefits attributed to SSA are taken into account in the aggregate analysis. For these studies, the share of SSA in the global estimated benefits was either obtained from the authors or was determined based on the area planted in SSA to improved varieties as a percentage of global adoption area.

Estimating costs by CGIAR centers

Costs are based on the percentage share of the CGIAR system total expenditure in SSA for the period 1971–2004, as reported by Lele et al. (2003) and in the 2003 and 2004 CGIAR financial reports (CGIAR, 2004; CGIAR, 2005). Some of the included benefits on wheat, maize, beans, and cassava derived from research by CIMMYT, CIAT, and IITA predate the establishment of the CGIAR. Thus, investments by these centers in SSA prior to joining the CGIAR system need to be accounted for as costs. In the absence of readily available data, research investments in SSA by these three centers from 1966–1970 were assumed to be at the same level as the total system costs estimated for 1971. This is likely to be an overestimate given the lag in establishing a center and starting a research program on the ground.²⁵

Estimating costs by NARS partners

Although the studies included in this review process and meta-analysis only include impact assessments of those technologies/products that can be traced to CGIAR research efforts, the benefits generated from these technologies could not have been realized without investments by NARS and other partners. Thus, throughout this paper, reference made to the contributions of the CGIAR refers to the joint partnership between CGIAR and NARS partners. In an ideal scenario, to account for the joint ownership (CGIAR and NARS) of the realized benefits, the total costs incurred by NARS and other partners should be included in the denominator of the aggregate analysis. In the absence of such aggregate-level data for non-CGIAR costs, the authors estimate the relative shares of the CGIAR and NARS partners' costs based on the documented total costs reported in the reviewed studies. They then extrapolate this ratio to the whole CGIAR portfolio investment in SSA of US\$3.26 billion in nominal dollars (US\$4.3 billion in \$2004). Table 11 illustrates how this ratio is derived.

Seven of the 23 reviewed impact studies provide cost estimates disaggregated by CGIAR center costs, and costs incurred by NARS, non-governmental organizations (NGOs), and other stakeholders. The seven studies represent about 2% of total CGIAR investment in SSA to date, and cover the following types of research products: improved varieties (Byerlee and Traxler, 1995; Rohrbach et al., 1999); biological control technology (Zeddies et al., 2001; Bokonon-Ganta et al., 2002); fodder bank technology (Elbasha et al., 1999); mechanical innovation (Rutherford et al., 2001); and integrated aquaculture/agriculture (IAA) (Dey et al., 2005). The share of NARS partners in total reported costs of a given project varies from less than 30% of a center's total investment (e.g., Zeddies et al., 2001), to six times the costs of a center's investment (Rohrbach et al., 1999). Most of these studies only reported those NARS costs that directly contributed to the assessed benefits. However, the reported NARS costs by the two studies that assess the impacts of crop improvement research (Byerlee and Heisey, 1996; Rohrbach et al., 1999) included all the

²⁵ It is also possible that the benefits included in the analysis may be due to research conducted by the CGIAR system in other regions (the spill-over effects). This means that by only including costs incurred by the CGIAR–NARS system in SSA, aggregate costs are underestimated.

Table 11. NARS costs as a percentage of CGIAR center costs in realizing benefits attributed to center investments: review of seven studies

Study	Costs reported by a study ^a (current US\$ million)			Comments about reported NARS costs	Adjustment factor applied to estimate NARS costs for the assessed project	Adjusted NARS cost (US\$ million)	Adjusted total cost on assessed benefits (US\$ million)	Percentage share in total costs		NARS costs as a percentage of CGIAR center costs
	CGIAR center costs	NARS and other partner costs	Total					NARS	CGIAR center	
Zeddie et al. (2001)	21.5	5.9	27.3	Includes only project costs ^b	None	5.9	27.3	21	79	27
Rutherford et al. (2001)	11.9	6.0	17.9	Includes only project costs ^c	None	6.0	17.9	33	67	50
Rohrbach et al. (1999)	3.0	18.3	21.3	Includes costs of the whole millet breeding program	2.50 ^d	7.6	10.6	71	29	250
Byerlee and Traxler (1995)	15.4	78.5	93.9	Includes NARS budget on all wheat improvement research	2.50 ^d	38.5	53.8	71	29	250
Bokonon-Ganta et al. (2002)	1.1	1.4	2.5	Includes only project costs ^b	None	1.4	2.5	56	44	129
de Groote et al. (2003)	0.4	1.5	1.9	Includes only project costs ^b	None	1.5	1.9	80	20	410
Dey et al. (2005)	2.0	1.3	3.3	Includes only project costs ^b	None	1.3	3.3	39	61	64
Total/average across surveyed studies	55.2	112.9	168.1			62.0	177.3	53	47	112

^a Total costs covering only the ex post period of impact analysis.

^b NARS costs are inclusive of costs incurred by NGOs and other donors (e.g., Gesellschaft für Technische Zusammenarbeit (German Agency for Technical Cooperation), Food and Agriculture Organization of the United Nations, and US Agency for International Development).

^c These are non-ILRI costs; but may include some costs by ICRISAT.

^d Source: Maredia and Byerlee (1996). Number refers to the percentage share of NARS costs in the total CGIAR-NARS crop improvement system that results in improved varieties that are center x center selected or center x NARS selected. Since the NARS costs reported by these two studies include NARS budget for the whole crop improvement program for that commodity (see the comments column), this ratio was used to estimate the NARS costs attributed to only the development of varieties that are center x center selected or center x NARS selected (i.e. the outputs/products which are the focus of the meta-analysis).

NARS costs towards a crop's breeding program. Since the benefits assessed and reported in this study for CGI research only include a subset of outputs of a NARS breeding program (i.e. improved varieties attributed to CGIAR crosses only), the reported NARS costs of these two studies were adjusted downward to bring the ratio of NARS–CGIAR costs to 2.5. This adjustment ratio is based on the cost analysis of the share of NARS costs in the global CIMMYT–NARS crop improvement system reported by Maredia and Byerlee (1996).²⁶

After adjusting NARS costs for the two CGI studies to include only those costs that directly contribute to the assessed benefits, the weighted average cost share across the sample of seven studies is 53% (or 112% of CGIAR costs). In other words, for every dollar invested by the CGIAR system in SSA that results in benefits, the NARS in aggregate invest US\$1.12 to realize those benefits. This reflects the true partnership between CGIAR and NARS in technology development and dissemination efforts. Even though the sample of studies (seven) used to derive this average cost share figure is quite small, for the lack of an alternative estimate, the authors have used this figure of average costs in the baseline analysis to derive total NARS costs and added those to the total CGIAR investments.²⁷ To test the sensitivity of the results to the estimated NARS costs, the authors also report the results by increasing the ratio to 2.5 (250%) and reducing it to 0.2 (20%).

Deflation and discounting

The reported benefits from each study²⁸ and the costs by CGIAR and NARS were recorded in nominal US dollars. Deflation or inflation of currency values was calculated using the US Producer Price Index to establish 2004 as the common base-currency year for all included costs and benefits. This was performed independently for each of the studies to account for different base-currency years. Once nominally adjusted, benefits from the included studies in a given scenario were aggregated to produce total annual benefit streams. These were discounted using a 4% real discount rate²⁹, which is consistent with prior benefit–cost analyses of long-term research and other public-sector investments (Bazon and Smetters, 2001; Raitzer, 2003). To test for the sensitivity of results, the discount rate was reduced to 0% and raised up to 10% to reflect a realistic range of potential returns to very long-term, private-sector alternative investments.

$$TV_u = \sum_{t=s}^n \sum_{i=1}^z \frac{B_{it}}{(1+r)^{t-T}} \quad TC_u = \sum_{t=f}^j \frac{G_t + N_t}{(1+r)^{t-T}} \quad BCR_u = \frac{TV_u}{TC_u}$$

²⁶ The interpretation of this ratio is that for every dollar spent by CIMMYT in crossing and early generation selection and testing, the NARS in aggregate spend US\$2.5 (in US\$ purchasing power parity) on selection and wide-scale yield testing of this material. At the official exchange rate, the NARS costs are estimated to be US\$1, in aggregate, to every dollar spent by CIMMYT (Maredia and Byerlee, 1996). However, to be conservative, we have used the higher estimated ratio based on US\$ purchasing power parity.

²⁷ This means that the denominator in the benefit–cost analysis includes total investment by the CGIAR–NARS system in SSA to date (from 1966–2004) of US\$3.26 billion + (US\$3.26 billion × 1.12) = US\$6.9 billion.

²⁸ Note that for global assessment studies, included benefits are those that are attributed to SSA, and for CGI research impact studies these only include benefits attributed to CGIAR-related germplasm.

²⁹ The discount rate used in the meta-analysis is the 'real' rate of interest, or observed rate of interest net of the expected rate of inflation. The discount rate of 4% in 'real' terms is more on the conservative side within the range of discount rates used for long-term public sector investments by governments in industrialized countries (major CGIAR system donors). The discount rates used in benefit–cost analyses for long-term investments typically range from 2–3% (e.g., recommended by the US Office of Management and Budget) http://www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html, 2.5–3.0% (e.g., used by provincial governments in Canada), to 3.5% (recommended by the UK Treasury Department) <http://greenbook.treasury.gov.uk/chapter05.htm#discounting>. As the real discount rate is essentially a risk- and inflation-free estimate of the long-term opportunity cost of capital, a good proxy is also the interest rate on a 10-year US Government Bond, less the inflation rate. This is also in the order of 2–3%.

The meta-analysis of aggregate costs and benefits can be expressed algebraically as follows:
where,

TV	=	total value of benefits assessed
u	=	scenario under which estimate is generated
t	=	year
T	=	2004 (the base year of the study)
s	=	start year of benefit period
n	=	end year of benefit period
i	=	particular study included
z	=	total number of studies reporting benefits/costs for a given scenario
B	=	benefit value of a study (in 2004 US\$)
r	=	discount rate
TC	=	total costs of CGIAR–NARS investments in SSA
f	=	first year of the cost series (1966)
j	=	most recent year of CGIAR investment (2004)
G	=	expenditures by the CGIAR system in SSA
N	=	costs by NARS partners
BCR	=	benefit–cost ratio

Aggregation of costs and benefits: results

Results of the meta-analysis

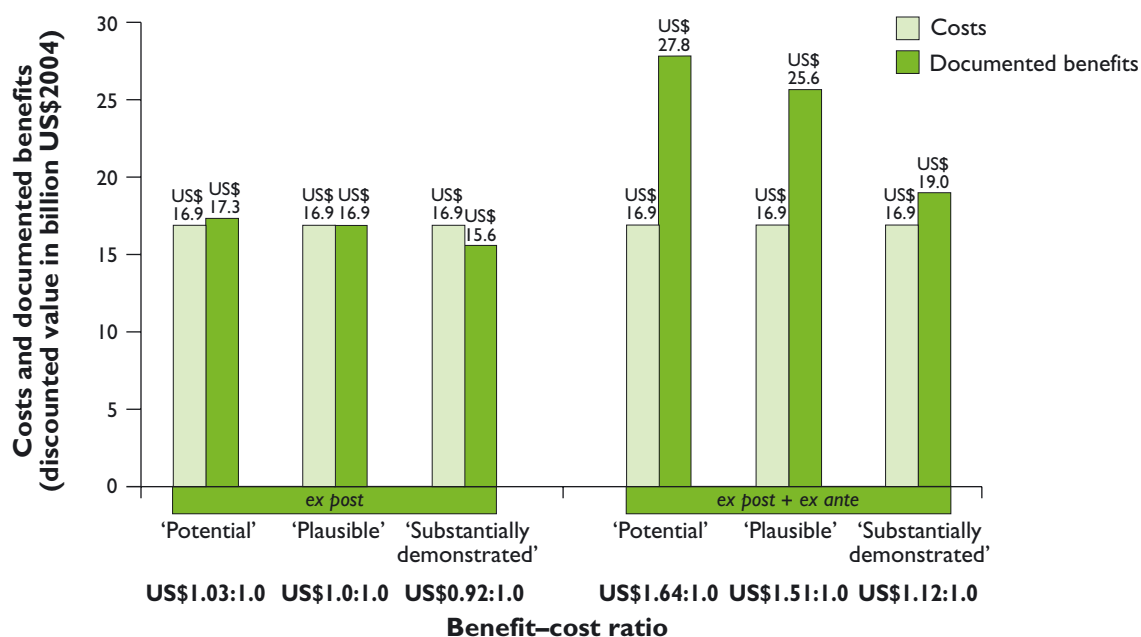
The aggregate total costs of the CGIAR–NARS partnership investment in SSA for the period 1966–2004 are estimated to be US\$9.2 billion (in real dollars). This translates to a present value (in 2004) of US\$16.9 billion. One of the questions addressed by this meta-analysis is: “How do the documented benefits of research in SSA, which are directly attributed to the CGIAR system, **compare with** these aggregate total investments to date?” Note that the BCRs or IRRs derived from the meta-analysis are not absolute values of indicators of the impact of CGIAR–NARS investments to date, as the studies reviewed do not quantify the value of all impacts of research in the region. Thus, these values should be considered conservative lower-bound estimates, since costs are total, but benefits are partial.

The benefits reported in the 23 assessments justify the entire CGIAR–NARS investment in SSA to date in all but one of the six scenarios considered for the meta-analysis (Figure 10 and Table 12).³⁰ The only sub-scenario where the present value of documented benefits is less than the present value of costs is the *ex post* subset of ‘substantially demonstrated benefits.’

The estimated ‘potential’ benefits give the most complete picture of possible benefits to have accrued to the CGIAR–NARS investment to date. However, these benefits include results that were rated low on the transparency and rigor criteria, and thus may not provide full confidence in the results. Total present value of ‘potential’ documented benefits is estimated at US\$17.3 billion in the *ex post* sub-scenario and US\$27.8 billion in the *ex post + ex ante* sub-scenario. Nineteen studies are included in the category of ‘plausible’ benefits. These benefits have been calculated with at least a moderate degree of rigor. Four of the 23 studies are eliminated from this category due to unclear or limited data sources for such key parameters as adoption and productivity changes. The aggregate lower-bound BCR is at least 1.0 in the *ex post* scenario and 1.5 in the *ex post + ex ante*. Similarly, the minimum IRRs are 4% and 8% respectively for the two scenarios. These are respectable returns considering the long-term nature of investments being considered.

³⁰ Since this is strictly an *ex post* assessment, no attempt is made to project the CGIAR–NARS costs beyond 2004 in any scenario. The documented benefits beyond 2004 that are included in the *ex post + ex ante* sub-scenario are projected benefits of past investments and do not require additional investment beyond 2004.

Figure 10. Comparison of estimated costs and documented benefits of joint CGIAR–NARS investment under three scenarios of aggregation of economic impact and two time periods



The scenario of ‘substantially demonstrated’ benefits provides highly robust estimates of aggregate benefits since it includes only those benefits that have been calculated with higher analytical rigor. The application of higher analytical rigor reduces the number of studies from 19 to 9 under this scenario. The criteria that excluded studies from this scenario primarily relate to the use of simple assumptions and data treatment, which lack sufficient justification in the assessments’ text.

As indicated in Figure 10, the BCRs based on the aggregation of ‘substantially demonstrated’ benefits are at least 0.92 and 1.12 for the *ex post* and *ex post + ex ante* sub-scenarios respectively. These results indicate that when the most conservative scenario of benefit aggregation and time period analysis are considered, documented benefits nearly match costs.

Under all the scenarios, close to 85% of documented total benefits stem from the biological control research assessed in four studies. More than 90% of these benefits are contributed by just one study assessing the impacts of biological control of cassava mealybug. Some 10–15% of total benefits are derived from improved varieties and about 1% of total benefits stem from other types of research assessed in four studies, namely, improved farm inputs and management practices.

While the benefits in the *ex post* sub-scenario are highly robust, it should be recognized that many research investments (e.g., cassava, cowpea, and sorghum³¹) that can be reasonably expected to accrue benefits are omitted. Also omitted are benefits realized in SSA from CGIAR research in other regions and those that spilled over from SSA to other regions. The estimated benefits do not account for the future continuation of benefits of research beyond the year of individual analysis (Table 12). Exclusion of these potential benefits that have been realized but not documented, and hence not included in the meta-analysis, makes the estimated BCRs in all the scenarios highly conservative. **Thus, the estimated BCRs and IRR**

³¹ Note that the three impact studies on sorghum included in the meta-analysis are variety- and country-specific studies covering the period from the 1980s to the 1990s. In the context of 2000, the combined adoption area represented by these three impact studies is less than a quarter of the estimated area planted to CGIAR-related improved sorghum varieties.

Table 12. Annual benefit and cost estimates for research investments of CGIAR–NARS partnerships under different scenarios of study selection

Year	Total CGIAR–NARS costs ^a	'Substantially demonstrated' benefits		'Plausible' benefits		'Potential' benefits	
		ex post	ex post + ex ante	ex post	ex post + ex ante	ex post	ex post + ex ante
1966	270.51	–	–	–	–	–	–
1967	259.45	–	–	–	–	–	–
1968	243.39	–	–	–	–	–	–
1969	225.22	–	–	–	–	–	–
1970	209.00	–	–	–	–	–	–
1971	194.49	–	–	–	–	–	–
1972	236.48	–	–	–	–	–	–
1973	255.88	–	–	–	–	–	–
1974	286.50	–	–	–	–	–	–
1975	347.50	–	–	–	–	–	–
1976	422.61	–	–	–	–	–	–
1977	473.03	–	–	–	–	–	–
1978	462.60	8.51	8.51	8.51	8.51	8.51	8.51
1979	456.67	14.32	14.32	14.34	14.34	14.34	14.34
1980	554.09	16.87	16.87	16.91	16.91	16.91	16.91
1981	546.68	14.88	14.88	14.96	14.96	14.96	14.96
1982	564.26	52.90	52.90	53.18	53.18	53.18	53.18
1983	575.85	192.26	192.26	193.01	193.01	193.01	193.01
1984	515.09	234.58	234.58	236.13	236.22	236.13	236.13
1985	534.97	364.52	364.52	367.86	368.07	367.86	367.86
1986	571.78	701.16	701.16	707.08	707.32	707.08	707.08
1987	585.69	848.14	848.14	852.66	852.75	852.66	852.66
1988	554.80	884.38	884.38	892.94	892.94	892.94	892.94
1989	588.80	798.71	798.71	807.18	807.18	807.18	807.18
1990	591.04	1,013.90	1,013.90	1,031.37	1,031.37	1,031.37	1,031.37
1991	570.70	1,125.41	1,125.41	1,151.95	1,151.95	1,151.95	1,151.95
1992	539.92	1,001.77	1,001.77	1,023.97	1,023.97	1,023.97	1,023.97
1993	485.01	968.24	968.24	995.04	995.04	1,000.45	1,000.45
1994	475.50	939.85	939.85	976.35	976.35	987.43	987.43
1995	464.78	815.72	815.72	853.24	853.24	869.80	869.80
1996	453.74	910.34	910.34	954.31	954.31	976.51	976.51
1997	453.05	706.82	706.82	775.39	775.39	803.84	803.84
1998	434.43	683.85	683.85	1,390.15	1,439.76	1,674.18	1,723.79
1999	434.13	637.15	637.15	699.44	1,399.35	736.97	1,675.59
2000	384.80	587.70	587.70	646.05	1,282.26	685.09	1,538.30
2001	403.80	553.88	553.88	593.53	1,198.58	593.84	1,405.25
2002	418.42	547.92	547.92	598.23	1,171.55	598.30	1,374.70
2003	421.38	504.92	504.92	541.70	1,063.80	541.84	1,249.31
2004	423.47	454.17	454.17	488.60	951.41	490.12	1,120.79
2005	–	–	435.01	–	914.98	–	1,078.53
2006	–	–	418.52	–	883.04	–	1,041.69
2007	–	–	404.58	–	844.22	–	998.18
2008	–	–	391.38	–	441.76	–	448.42
2009	–	–	372.14	–	420.59	–	422.08
2010	–	–	354.27	–	400.85	–	402.86
2011	–	–	340.38	–	385.17	–	387.83
2012	–	–	324.92	–	361.47	–	364.93
2013	–	–	314.12	–	349.27	–	353.71
2014	–	–	3.31	–	37.10	–	42.73
2015	–	–	3.18	–	35.68	–	42.72
2016	–	–	3.06	–	34.30	–	41.13
2017	–	–	2.94	–	32.99	–	32.99
2018	–	–	2.83	–	31.72	–	31.72
2019	–	–	–	–	27.77	–	27.77
2020	–	–	–	–	10.68	–	10.68
Aggregate	16,889	15,583	18,954	16,884	25,645	17,330	27,826

^a Present value in 2004 US\$ million

should be viewed as the lower bounds of possible ratios and rates of return. These are likely to be substantially higher in actuality.

Sensitivity analysis

Figure 11 shows the sensitivity of the lower bounds of BCRs to real discount rates. If the real discount rate is raised to 8% or more, these ratios become less than unity for all scenarios of aggregate benefits and sub-scenarios of benefit projections. The BCRs are more sensitive to changes in the real discount rate, and the sub-scenarios to benefits included (*ex post* versus *ex post + ex ante*) rather than to scenarios of benefit aggregation ('plausible' and 'substantially demonstrated'). This is largely due to the fact that a single study accounts for the vast majority of benefits in all scenarios, while the other smaller studies that are not included in the more selective scenarios do not raise aggregate benefit levels significantly.

The results of this meta-analysis are probably more accurate if the seven impact assessment studies sampled are representative of the supplementary costs of NARS on CGIAR outputs. However, if they are not, these results may over- or under-estimate the true BCRs. To test the sensitivity of the results to the NARS costs included in the denominator, the BCRs for the 'substantially demonstrated' and 'potential' scenarios were estimated by varying the NARS–CGIAR cost ratio from 25–250% (Figure 12).

In the base scenario where the estimated NARS costs are 112% of total CGIAR system costs, the minimum BCR is more than unity in the *ex post + ex ante* sub-scenario but less than unity in the *ex post* sub-scenario. The estimated benefits in the *ex post* sub-scenario can justify total CGIAR–NARS investments if NARS costs are less than 100% of the known total CGIAR costs to date. Similarly, the estimated benefits in the *ex post + ex ante* sub-scenario can justify total CGIAR–NARS investments for NARS costs of up to 130% of CGIAR costs. For the all-inclusive scenario of 'potential' benefits, the estimated benefits can justify total investments by CGIAR–NARS for a cost share assumption of up to 250%.

Figure 11. Sensitivity of aggregated benefit–cost ratios to real discount rates under six scenarios

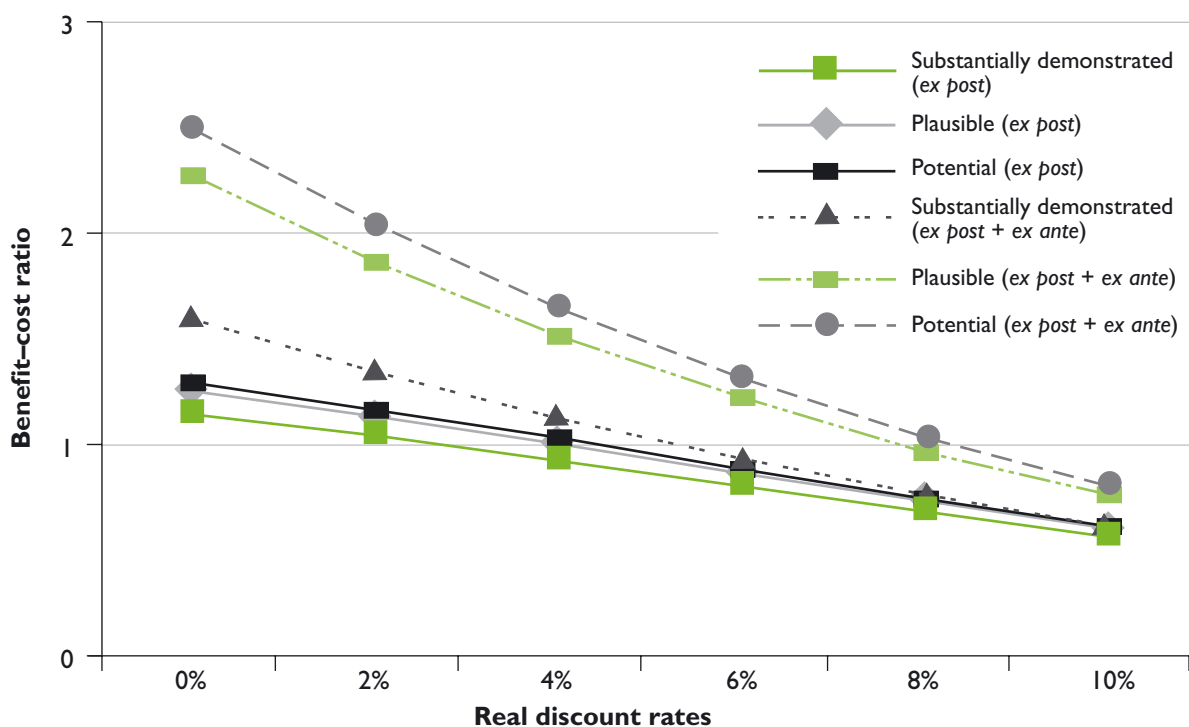
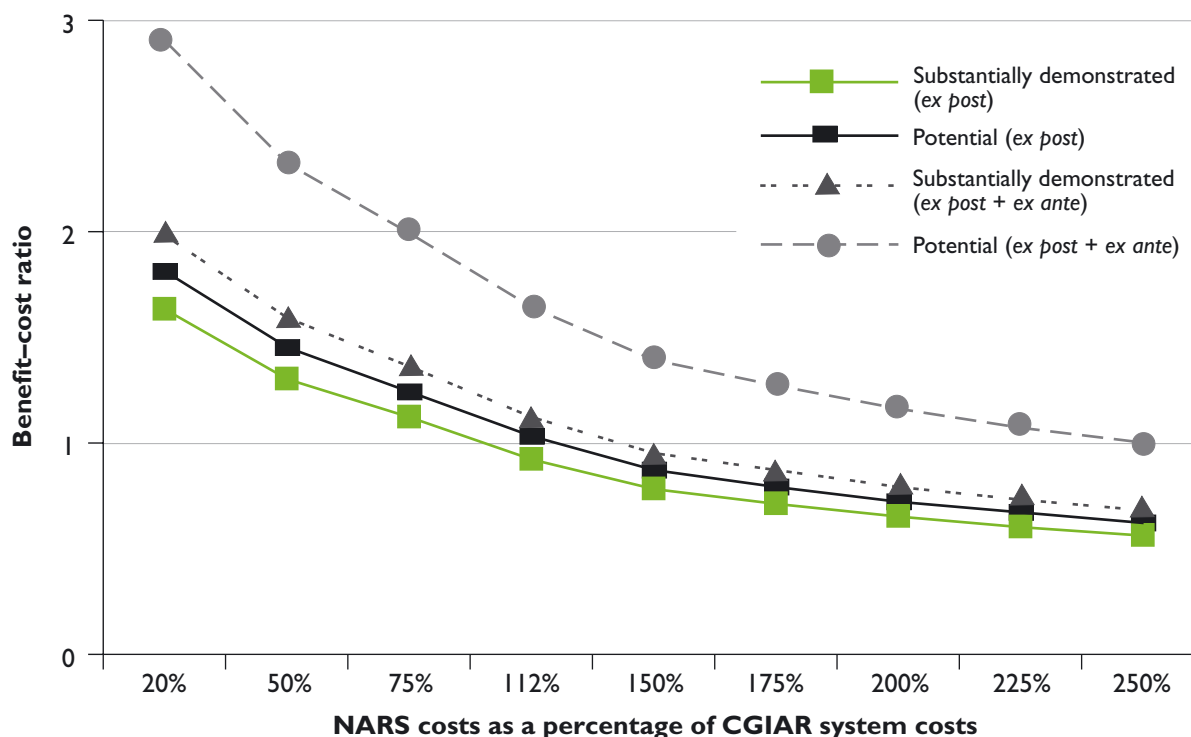


Figure 12. Sensitivity of aggregated benefit–cost ratios to NARS costs under the ‘substantially demonstrated’ and ‘potential’ benefits scenarios



It is very unlikely that the NARS costs in the joint CGIAR–NARS partnership will be less than 25% of CGIAR investment, given the fact that none of the surveyed impact studies reported such a low cost share by NARS in the assessed projects. It is also unreasonable to assume that the aggregate NARS costs in this partnership will be more than 250% of CGIAR investment, given the fact that the median cost share reported in the surveyed studies is about 130%. The main result of the baseline analysis, which shows that investments by CGIAR–NARS are fully recovered if benefits considered are as reported or projected for 10 years hence, holds true for a reasonable range of NARS cost share assumptions. Thus, it is quite reasonable to conclude that the results of this meta-analysis are robust for a large range of plausible NARS cost–share assumptions.

Discussion of results

One of the purposes of this paper is to assess available evidence of agricultural research impact in order to offer a systematic answer to the question: “Has investment by the CGIAR–NARS partnership in SSA been justified by documented benefits to date?” Based on the results of the meta-analysis, the answer to this question is, “Yes, in five out of six scenarios of extreme assumptions, the documented benefits (which represent 5% of the total invested) do exceed the investments to date of the entire CGIAR–NARS partnership in SSA.” However, this answer needs to be qualified by several observations and explanations that give a more complete understanding of the impacts of agricultural research in SSA.

First, although the aggregate benefits exceed aggregate costs, the documented levels of the impact of CGIAR research in SSA do not match those calculated for the overall global system (Raitzer, 2003). Second, the benefits documented for the region are relatively unique in that most are generated from biological control

research, few are generated by CGI, and none or very insignificant levels are generated by other types of research. The summary of studies included in the meta-analysis in Table 13 depicts the coverage of different types of outputs, their corresponding time periods, and assessed benefit values. This summary also illustrates the gaps in the coverage by depicting areas of research not included in the meta-analysis.

Impacts of research on crop germplasm improvement

Estimates of CGI research benefits in the meta-analysis cover eight food crops – beans, cassava, maize, millet, potato, rice, sorghum, and wheat. Together, they contribute US\$2.4 billion (14% of total estimated benefits) towards the present value estimates of total potential benefits (US\$17.3 billion). These documented impacts are attributed to six CGIAR centers and their NARS partners: ICRISAT (US\$440 million for millet and sorghum); IITA (US\$418 million for maize); Centro Internacional de la Papa (CIP; International Potato Center) (US\$369 million for potatoes); CIMMYT (US\$337 million for maize and wheat); WARDA (US\$321 million for rice); CIAT (US\$276 million for beans); and CIAT/IITA (US\$250 million for cassava). The impact studies on maize, rice, wheat and beans are comprehensive in geographic coverage and include benefits aggregated over the entire SSA or a sub-region. However, the included benefits for sorghum, millet, and potato are examples of benefits realized from the adoption of specific varieties in specific countries.

The sparse coverage of assessed benefits (both in terms of the time period and crops) included in the meta-analysis indicates that the estimated benefits of US\$2.4 billion for CGI research are an underestimate of its potential benefits.

The first factor contributing to underestimated benefits is the fact that the included benefits represent the impacts realized on about 8.9 million ha of cropped area planted to CGIAR-related varieties.³² This implies that impacts of CGIAR-related varieties on 21% of estimated adoption area (equivalent to 2.3 million ha of area planted to CGIAR-related varieties in the late 1990s) are not included in the meta-analysis (Table 6).³³ These potential benefits include important food crops such as cowpea, and the undocumented impacts of sorghum, millet, and potato for which the estimated benefits in the meta-analysis only represent specific countries and varieties.

The second factor is that the time coverage of benefits is not comprehensive (Table 13). There are gaps in the time period covered, even though the evidence suggests adoption of CGIAR-related varieties for the seven crops in years following and prior to those covered by the study (Evenson, 2003). Based on the estimated adoption of improved varieties of these CGIAR-mandated food crops and their contributions to yield growth, Evenson (2003) estimated the rate of return of the contribution of international agricultural research centers to CGI research in SSA at 68%.³⁴ The single year estimates included in the present study for important food crops like maize, rice, and cassava, and the gaps in the covered time period for wheat thus reflect uncounted benefits, which may be in hundreds of millions of US\$.

Impacts of new or improved agricultural inputs

The meta-analysis includes two studies on new or improved agricultural inputs that increase the efficiency of a farming system by either reducing the factor costs (labor or capital), or increasing the production of

³² This is based on the area planted to CGIAR-related improved maize varieties in late 1990s (3.6 million ha), wheat (1.8 million ha), cassava (1.6 million ha), rice (1 million ha) and beans (0.26 million ha); and area planted to CGIAR-related varieties reported in each study for sorghum (0.56 million ha), millet (0.13 million ha), and potato (0.06 million ha).

³³ This is a crude estimate and does not take into account the variation over time in total area planted to different crops and the adoption of CGIAR-related varieties. It is also based on the assumption that the adoption claims documented in Table 6 are credible and plausible.

³⁴ Note that this rate of return is an estimate of returns to investments on only CGI research. Hence it is not comparable with the estimated IRR of the current analysis, which includes all investments by the CGIAR–NARS system to date.

Table 13. Potential aggregate estimates of benefits and periods of coverage of studies included in the ex post scenario

Examples of CGIAR involvement in research/activities in SSA		Periods of coverage												Present value of total estimated benefits (2004 US\$ million)		
		1975	1980	1985	1990	1995	2000									
CGI (breeding and biotechnology)	Bean s ¹															276.5
	Cassava ²															250.3
	Cowpea															
	Groundnut															
	Maize (IITA) ³															418.1
	Maize (CIMMYT) ⁴															22.9
	Millet ⁵															231.2
	Pigeonpea															
	Plantain															
	Potato ⁶															369.0
	Rice ⁷															23.6
	Rice ⁸															208.6
	Rice ⁹															88.9
	Sorghum (Sudan) ¹⁰															113.3
	Sorghum (Mali and Chad) ¹¹															80.7
	Sorghum (Zimbabwe) ¹²															14.8
	Soybean															
	Sweet potato															
Wheat ^{13,14,15}															314.5	
Yam																
Livestock																
Fisheries																
Agroforestry																
Processing																
Storage																
Farm machinery/tools ¹⁶															0.8	
Feed/forage crops ¹⁷															55.5	
Vaccines																
Crop																
Agroforestry																
Livestock																
Aquaculture ¹⁸															1.3	

Table 13. Potential aggregate estimates of benefits and periods of coverage of studies included in the ex post scenario (continued)

Examples of CGIAR involvement in research/activities in SSA	Periods of coverage										Present value of total estimated benefits (2004 US\$ million)	
	1975	1980	1985	1990	1995	2000						
IPM	Biological control (cassava mealybug) ¹⁹											13,911.8
	Biological control (mango mealybug) ²⁰											529.5
	Biological control (water hyacinth) ²¹											217.9
	Biological (cassava green mite) ²²											193.4
Integrated natural resource management	Other IPM methods											
	Management of terrestrial resources (soils, flora, and fauna)											
	Watershed management											
	Cropping system ²³											1.3
Biodiversity	Farming practices											
	Management of water resources											
	Management of forest resources											
	Germplasm collection/exchange											
Policy	Genetic resource conservation											
	Farm-level biodiversity											
	Genetic linkage maps											
	Technology development/adoption (food, forest, livestock, and fisheries)											
Strengthening NARS	Improved NRM management											
	Research methodologies											
	Research networks (regional)											
	Training											
	Capacity for policy analysis											
	Capacity to conduct research											
	All											17,330

Sources: 1. Johnson et al. (2003a); 2. Johnson et al. (2003b); 3. Manyong et al. (2003); 4. Morris et al. (2003); 5. Rohrbach et al. (1999); 6. Rueda et al. (1996); 7. Tre (1995) for only Sierra Leone; 8. Dalton and Guei (2003); 9. Fall (2005); 10. Ahmed et al. (1994); 11. Yapi et al. (1999); 12. Anandajayasekaram et al. (1995); 13. Byerlee and Traxler (1995); 14. Heisey et al. (2002); 15. Lantican et al. (2005); 16. Rutherford et al. (2001); 17. Elbasha et al. (1999); 18. Dey et al. (2005); 19. Zeddies et al. (2001); 20. Boknonon-Ganta et al. (2002); 21. de Groot et al. (2003); 22. Coulibaly et al. (2004); 23. Ajayi et al. (2005)

final outputs (crop and animal yields). The improved agricultural inputs under study were the broadbed-maker plough, and the fodder bank technology, developed by ILRI–NARS partnerships.

Unlike CGI research, which remains an ongoing program activity at most commodity centers, these studies represent examples of projects with specific objectives that are specifically undertaken for a period of time. The broadbed-maker plough was an outcome of a joint collaborative project involving ILRI, ICRISAT, and an Ethiopian NARS from 1986–1998. The estimated total benefit of US\$0.8 million (present value) for this technology is one of the lowest estimates included in the meta-analysis. The reason for this is mainly its low level of adoption (due to the weight and cost of the technology). This technology was estimated to be in use on only 625 ha of planted wheat and teff at the time of the project analysis (1999), 14 years after the project was initiated (Rutherford et al., 2001). The estimated area of adoption represents about 0.2% of the potential area on which this technology could be applied. This is the only study in the meta-analysis where the estimated *ex post* benefits do not exceed the total project cost. In order to realize positive net benefits, the study estimated that adoption levels would need to increase significantly from the observed 625 ha to 213,000 ha (0.2–4.2% of the total wheat and teff area in Ethiopia).

The study by Elbasha et al. (1999) assesses the benefits of ILRI–NARS research investments in fodder bank technology from 1978–1997. The technology was promoted in West Africa as a method of fencing and planting forage legumes to alleviate shortages experienced by agropastoralists during the dry season. The estimated *ex post* benefits of US\$55 million (present value) stem from the impact of this technology on increased meat and milk production. These benefit levels are based on an estimated adoption rate by the 1997 of 27,000 farmers (19,000 ha) across 16 countries in West Africa. Assuming that 1% of highly suitable land could potentially be planted with the forage legume promoted by this project, the estimated adoption rate represents a little over one-third of its potential (Elbasha et al., 1999).

The estimated adoption levels of 625 ha for the broadbed-maker plough and 19,000 ha for the fodder bank technology are small adoption estimates when compared with the CGI research outputs. However, the estimated realized benefits per hectare of adopted area per year for these two technologies are in the range of US\$130–180, which are comparable with the average benefits per year and per hectare of the adoption of improved crop varieties.

These two studies illustrate the complexity of realizing net positive benefits from research on technologies developed for a particular target population that require significant resources for their dissemination. Unlike improved varieties, these technologies spread slowly on their own, and considerable facilitation in terms of training, information, and materials is required to promote them.

It is difficult to assess the extent to which the total estimated benefits of CGIAR–NARS research on improved agricultural inputs (US\$56 million in 2004) represent the actual benefits that may have been realized from CGIAR–NARS investments in this category. Table 8 lists studies that assess the adoption and farm-level impacts of a fodder shrub technology promoted to smallholder dairy farmers by ICRAF and the Kenya Agricultural Research Institute (Franzel et al., 2002). This study reports the adoption of this technology reaching less than 1% of Kenya's smallholder dairy farmers (2000). A more recent estimate of adoption of this technology shows its spread to about 48,000 smallholder dairy farmers in Kenya (7–8% of potential), and about 38,000 farmers in neighboring Tanzania, Uganda, and Rwanda (Franzel and Mwanda, 2005).

Impacts of biological control research

The documented benefits of research on biological control of several pests that threaten the production of major commodities in SSA contribute more than 80% of the total estimated benefits in the meta-analysis.

These benefits stem from four IITA-led collaborative projects on biological control of the cassava mealybug (Zeddies et al., 2001), cassava green mite (Coulibaly et al., 2004), mango mealybug (Bokonon-Ganta et al., 2002), and water hyacinth (de Groote et al., 2003). The estimated *ex post* discounted benefits from only one study, the cassava mealybug, recovers 80% of the total investments by the CGIAR–NARS partnership in SSA to date. These benefits are quite significant and allude to the considerable success of this program but also show that the results and conclusions drawn from the meta-analysis rely heavily on evidence from the cassava mealybug study. Total documented benefits to date from the introduction of *Apoanagyrus lopezi* (the control agent) to control the cassava mealybug are estimated at US\$13.9 billion. This figure is derived from the value of crop losses averted on about 9 million ha of cassava harvested in SSA. These benefits are attributed to the mass-rearing of *A. lopezi* and its release in about 150 sites across 20 countries over several years in the early 1980s. This case study on cassava mealybug is the most comprehensive in terms of geographic coverage in the meta-analysis. The results from Zeddies et al. (1999) confirm the projected high returns from an earlier impact study by Norgaard (1988) on the same technology.³⁵

The other impact studies of biological control included in the meta-analysis are limited in geographic scope and time, and thus explain the lower estimated total discounted benefits (e.g., US\$529 million for mango mealybug and US\$218 million for water hyacinth) relative to cassava mealybug (Table 13). The benefits of the control of mango mealybug are derived from the research, rearing and release of the parasitic wasp (the control agent) at several sites in Benin from 1988–1993 by IITA–NARS partners. The benefits are estimated as the difference in the value of mango production before and after the introduction of the control agent at a household level. The estimated gain per household in mango production is then extrapolated to the entire country of Benin based on the number of households producing mangoes and the proportion of area affected by the control agent. The actual benefits of the mango mealybug control program are estimated to be much higher than documented by Bokonon-Ganta et al. (2002), since they did not include the benefits in other Central African countries where the control agents were later disseminated at little additional cost.

The study on the impacts of the biological control of water hyacinth is limited to southern Benin (de Groote et al., 2003). The estimated total benefits of US\$218 million are derived from averting lost revenues for men (mostly fishing) and for women (trade) as a result of the reduction in the water hyacinth cover in rivers and lakes. Similarly, the study by Coulibaly et al. (2004) assesses impacts of research on biological control of cassava green mite in Nigeria, Ghana and Benin. The impacts of this research are derived from the value of increased cassava yields across the areas covered by the biological control agent.

The benefits in the meta-analysis of the biological control programs show that classical biological control is a cost-effective and sustainable way of averting economic and environmental losses due to pests (Alene et al., 2005). However, the estimated total benefits do not capture all the benefits from the CGIAR centers regarding biological control and other integrated pest management (IPM) technologies. Additionally, actual benefits would be expected to be higher than those highlighted in the meta-analysis since the three studies included capture only the conventional financial benefits of biological control of pests, while the benefits to ecological and human health have not been estimated.

Impacts of new or improved management practices and research on natural resource management

The evidence of impacts in this area of CGIAR research is insignificant (US\$2.6 million in present value) compared with the total documented discounted benefits of US\$17.3 billion. These benefits are derived

³⁵ Since both the studies deal with the same technology, only the more recent study by Zeddies et al. (1999) is included in the meta-analysis. The study by Zeddies et al. is based on much more reliable data than those available to and reported by Norgaard (1988).

from two recent studies on the impact of improved integrated aquaculture–agriculture (IAA) management practices (Dey et al., 2005), and the impacts of the fertilizer tree fallow system (Ajayi et al., 2005). The two studies assess the impacts of these technologies related to natural resource management (NRM) in Malawi and Zambia respectively. The benefits of these technologies (US\$1.3 million each in present value) are derived from increased productivity of farm outputs directly affected by improved management practices. These estimates do not include any environmental, social, or health benefits, and are therefore considered as lower bounds of potential impacts. The results allude to the location-specificity of such technologies, and the dependence on local governments and NGOs in extending them to realize wider-scale impacts.

The missing impacts of research in the meta-analysis: what do they suggest?

As illustrated in Table 13, the meta-analysis includes a small number of studies representing three major types of research outputs: improved varieties; improved inputs; and biological control. The absence of notable impacts of other types of research outputs in which the CGIAR has invested significant resources is quite apparent. This raises a question of whether these missing benefits are due to the lack of documented impacts, or the lack of impact itself. Some of the important missing benefits include: research on breeding improved varieties of cowpea, pigeonpea, plantain, soybean, sweet potato, and yam; genetic improvement of fisheries; NRM; research on biodiversity; enhancing governance; improving policy; and strengthening NARS.

However, for some commodity research such as that on groundnut, sorghum, rice, millet, and potato, the evidence of documented adoption suggests that the missing benefits are principally due to the lack of assessment rather than lack of impact. This also holds true for some types of research under the category of integrated natural resource management. Several studies were found that document the diffusion and adopter-level impacts of technologies such as improved fallow, fertilizer trees, alley farming, and no-till (Manyong et al., 1999; Ekboir et al., 2002). However, due to the lack of estimated benefits, these studies are not included in the meta-analysis. Some of the studies document significant adoption in recent years and thus project substantial benefits in the future (Ajayi et al., 2005; Dey et al., 2005). Thus, the estimates of adoption and the projected significant benefits of some of these technologies suggest that investments in this type of research are likely to yield positive benefits. Their exclusion from the meta-analysis is a reflection of the early stages of adoption (thus making it difficult to estimate *ex post* benefits), and not a lack of impact potential.

Nevertheless, the currently available evidence that environmental protection and policy-oriented research have generated substantial regional benefits is rather limited when compared to productivity-enhancing investments in CGI and biological control. While methodological limitations prevent a definite conclusion that such areas of CGIAR research have had few actual benefits, there is much more uncertainty about the returns of these investments. This uncertainty may reduce expected benefits from investments in these areas.

Moreover, there may be some reason to expect that actual levels of impact are likely to be limited. Effective application of policy and environmentally oriented research findings often require substantial local implementation capacity as recommendations are embedded in local regulatory frameworks and the actions of other agencies. Therefore, if regulations are not enforced due to limited organizational capacity, ineffective institutions, and/or problems of corruption, the impact of such research will be constrained. Thus, in the context of SSA, where local implementation capacity is particularly limited, the benefits from such activities may be especially restricted.

Increased CGIAR resources have been devoted to research in policy and environmental protection in the region, while investments in productivity-enhancing research have stagnated or declined in recent

years. The rationale for this shift is not entirely clear, and may be somewhat questionable in light of the particular uncertainty that is characteristic of the potential impacts of environmental and policy-oriented research. Taking this into account, the CGIAR centers need to better define how and why investment in these areas should be realistically expected to benefit large numbers of Africa's poor.

The following observations summarize the benefit–cost meta-analysis:

1. The total investments by the CGIAR–NARS partnership in SSA to date are estimated at US\$16.9 billion (US\$2004). The documented total benefits aggregated across all (*ex post* + *ex ante* sub-scenario) the 'potential', 'plausible', and 'substantially demonstrated' scenarios fully recover this total investment to date.
2. If only reported benefits to 2004 are considered, in at least one extremely conservative scenario, the aggregated benefits are not enough to cover the total investments to date by the CGIAR–NARS partnership. The estimated deficit in the level of *ex post* benefits to justify the total CGIAR–NARS costs is US\$1.3 billion (in compounded US\$2004).
3. Several missing or non-quantified estimates of 'plausible' or 'substantially demonstrated' benefits for which adoption is documented, and/or time coverage is limited suggest that the actual deficit may be lower than reported in this assessment, or non-existent. **The BCRs and the IRRs reported in this study should therefore be viewed as the lower bounds of possible ratios and rates of return, which are likely to be substantially higher in actuality and which will grow over time.**

Limitations of the benefit–cost meta-analysis

The most important limitation of this analysis is that the impact assessment coverage of research investments by the CGIAR has been neither systematic nor comprehensive. The presence of a number of research outputs with high observed levels of adoption but no impact assessments, suggests that some likely impacts have not been quantified. If such is the case, the results presented here are certainly biased downwards. Similarly, the exclusion of any *ex ante* projections of continuation of aggregate benefits prior to and beyond the years of analysis also creates a downward bias in the results.

The validity and accuracy of the meta-analysis approach used in this study depends upon a number of key assumptions. The analysis is based on documented studies that have only assessed positive benefits of CGIAR–NARS research efforts. No systematic effort has been made to assess and quantify the impacts of unintended or inappropriate outputs within the CGIAR. If CGIAR research in SSA has indeed led to technologies or products that may have had negative impacts, the results presented in this assessment may be an overestimate of aggregate benefits; the estimated BCRs may not be the lower-bound potential impacts as claimed. However, given the problem of attribution and lack of data availability, no attempt is made to account for negative impacts.

The limited number of studies included in the assessment makes it difficult to conduct any comprehensive analysis of the CGIAR's total investment portfolio. While the present analysis demonstrates whether past investment in research in SSA has been minimally justified by known and measurable benefits, the results are of limited relevance to future allocation of CGIAR investments. Due to attribution difficulties for many research areas, it should be recognized that limited documented impact in certain areas does not necessarily mean that benefits have not been generated.

The analysis is based on secondary sources of data (i.e. other impact studies) and as such, depends on the clarity of the text of published reports or data files received from the study authors. Hence, the data used

in the meta-analysis are not free from interpretation errors. In some cases, these assumptions may over- or underestimate the methodological sophistication of the included analyses, thus affecting the placement of a study within the three scenarios (potential, plausible, and substantially demonstrated).

The approach presented for the aggregate benefit–cost analysis points to the difficulty of estimating the NARS costs when data are limited. As such, the results of these analyses are based on assumptions and parameter values derived from a small sample of studies in the review list. If these assumptions are incorrect, or if the CGIAR–NARS cost ratio used is not representative of true values, the results may over- or underestimate the benefits attributed to the CGIAR system. However, for plausible values of cost ratio, the results suggest that the BCRs are close to or greater than unity.

5. Recommendations for Future Assessment Activities by International Agricultural Research Centers and the Standing Panel on Impact Assessment

The present study has observed a number of trends in the patterns of impacts documented in SSA that merit further investigation. The results and conclusions drawn from the meta-analysis rely heavily on the evidence of benefits from one impact study on the biological control research of cassava mealybug (Zeddies et al., 1999). This reduces the weight of the results even though the aggregate benefit estimates are based on the most conservative assumptions. More evidence of large-scale impacts from diverse areas of research is therefore urgently needed to validate the results and conclusions of this meta-analysis.

The authors had a rich pool of adoption literature from which to choose. However, most of these studies were of factors affecting adoption, which, although useful for informing research planning, do not provide all of the information necessary for large-scale estimates of research benefits.

A fairly substantial pool of large-scale adoption estimates do exist for an array of CGI activities. About two-thirds of the area represented by these estimates has been subjected to further rigorous *ex post* impact assessment. However, many of these assessments on important food crops (e.g., maize, rice, cassava, and wheat) have only estimated benefits from one single year. This means that substantial likely impacts realized from adoption over longer time periods, wider geographic areas, and more food crops (e.g., cowpea, sorghum, and groundnut) have escaped assessment, and conclusions about impacts in the region are thus inherently conditional. Clearly, additional work is needed to assess the impact of these CGI efforts thoroughly. More comprehensive studies of the impacts of CGIAR–NARS research akin to Byerlee and Traxler (1995) are needed to document impacts of these important food crops in SSA.

Comparatively little rigorous evidence exists of large-scale adoption or impact in the region from outputs other than those of biological control research or CGI. Given widely acknowledged methodological difficulties in the impact assessment of certain research outputs (such as policy-oriented information), it cannot be conclusively interpreted that these activities have had no impact. This observation certainly warrants further investigation by SPIA. Other than for productivity enhancement, there are no major large-scale studies (e.g., in NRM, policy, or biodiversity conservation) of the impacts of CGIAR research in SSA, yet resources allocated to such studies are continuing to increase. This points to the need for a serious evaluation of the impacts of these areas of research to better inform research priority setting within the CGIAR system.

To address this issue comprehensively, improved assessment methods for research areas that are difficult to assess are also needed. SPIA's ongoing NRM impact assessment study and impact assessment studies on policy-oriented research may make important contributions in this regard. With methodological progress, perhaps a new array of research benefits will be revealed from these research activities.

It must also be noted that many of the older research activities with little evidence of extensive adoption or impact are fairly conventional productivity-oriented farm-level technologies that should pose fewer

methodological problems for conventional impact assessment. While there have been reviews of factors affecting adoption in the region, no analysis to date has systematically exploited the full extent of these studies. Thus, in a follow-up phase, it may be useful to quantitatively investigate the prevalence of different observed adoption constraints for these technologies in the SSA context.

6. Conclusions

While the aggregate picture of SSA is often depicted as gloomy, there has been encouraging progress in some parts of the continent. However, this progress and the causal links between agricultural research and developmental impacts are often less obvious in SSA than in other regions. It is in this context that this study has attempted to inventory, synthesize and assess documented impacts of CGIAR–NARS partner research.

The review of documented impacts of CGIAR research has revealed not only what the impacts are, but also the gaps in impact assessment coverage. The majority of the studies reviewed assess productivity impacts of new technologies. Very few studies were found that measure or document the social, equity, environmental, health, and other types of impacts of agricultural research. This is not peculiar to the SSA region, but represents the profile of the impact assessment literature globally, and reflects the fact that the methodology for quantifying productivity impacts of research outputs or outcomes is much more advanced than the methodology for quantifying other types of research impacts.

The results of the meta-analysis of aggregate costs and benefits indicate that in all but one scenario, the aggregate benefits generated from documented impacts exceed the total investments in CGIAR–NARS research in SSA to date. These estimates are based on extremely conservative assumptions and indicate that this is a rare achievement in a region that is more often recognized for its development failures than its successes. This conclusion, however, goes hand-in-hand with the following observations about the documented impacts.

First, the documented levels of impact of CGIAR research in SSA do not match those calculated for the overall global system (Raitzer, 2003). Furthermore, the benefits documented for the region are relatively unique in that more than 80% of the benefits are generated by one study on the biological control of cassava mealybug. This makes it difficult to draw any strategic conclusions about the total investment portfolio of the CGIAR in SSA.

Second, it should be noted that few of the documented benefits are generated by CGI. This stands in marked contrast to observations at a global level, where more than three-quarters of CGIAR research benefits result from such activities (Raitzer, 2003). When it is considered that CGI research by international agricultural research centers has contributed to varieties cultivated over an estimated 11 million ha in SSA, this dichotomy becomes particularly apparent. Even if yield gains have been slight, it seems that improved documentation of the impacts of such extensive adoption should raise aggregate benefits for the region considerably.

Third, compared with the rest of the world, a higher proportion of the expenditure of the CGIAR in SSA has been in the areas of NRM research, strengthening of NARS, and policy-oriented research. However, the lack of documented impacts for this research in SSA begs the question: “Is this due to well-recognized difficulties in the attribution and quantification of such benefits (Schuh and Tollini, 1978; Ryan, 2002; and Kelley and Gregersen, 2003), or is it due to lack of impact itself?” Until appropriate methods are better developed for these research areas, this question cannot be fully answered.

To reinforce and validate the results of the meta-analysis that the CGIAR–NARS research partnerships in SSA have generated net positive gains, CGIAR centers and SPIA should invest resources to document evidence of large-scale impacts from areas of research that present attribution difficulties. Once relevant assessment methods are developed and coverage is expanded, it is almost certain that many additional benefits will be revealed, and the BCRs reported here will prove to be substantial underestimates.

References

- Ahmed M.M., Masters W.A., and Sanders J.H. 1994. Returns to research in economies with policy distortions: hybrid sorghum in Sudan. *Agricultural Economics*, 12: 183–192.
- Ahmed M.M., Sanders J.H., and Nell W.T. 2000. New sorghum and millet cultivar introduction in sub-Saharan Africa: impacts and research agenda. *Agricultural Systems*, 64(1): 55–65.
- Ajayi O.C., Place F., Kwesiga F., and Mafongoya P. 2005. *Fertilizer Trees, their Development, Socio-Economic and Ecological Impacts in Southern Africa*. Draft submitted to CGIAR Standing Panel on Impact Assessment. World Agroforestry Centre: Nairobi, Kenya.
- Alene A.D., Neuenschwander P., Manyong V.M., Coulibaly O., and Hanna R. 2005. *The Impact of IITA-Led Biological Control of Major Pests in Sub-Saharan African Agriculture: a Synthesis of Milestones and Empirical Results*. International Institute of Tropical Agriculture: Ibadan, Nigeria.
- Alston J.M., Chan-Kang C., Marra M.C., Pardey P.G., and Wyatt T.J. 2000. *A Meta-Analysis of Rates of Return to Agricultural Research and Development: Ex Pede Herculem?* IFPRI Research Report 113. International Food Policy Research Institute: Washington DC, USA.
- Anandajayasekeram P., Martella D.R., Sanders J., and Kupfurma B. 1995. *Report on the Impact Assessment of the SADC/ICRISAT Sorghum and Millet Improvement Program. Volumes I and II*. Southern African Development Cooperation: Gaborone, Botswana.
- Baker J. 2000. *Evaluating the Impact of Development Projects on Poverty: a Handbook for Practitioners*. World Bank: Washington DC, USA.
- Bantilan M.C.S. and Deb U.K. 2003. Impacts of genetic enhancement in pearl millet. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Bantilan M.C.S., Deb U.K., and Nigam S.M. 2003. Impacts of genetic improvement in groundnut. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Baur H., Bosch M., Krall S., Kuby T., Lobb-Rabe A., Schütz P.T., and Springer-Heinze A. 2001. *Establishing Plausibility in Impact Assessment*. Deutsche Gesellschaft für Technische Zusammenarbeit: Eschborn, Germany.
- Bazelon C. and Smetters K. 2001. Discounting in the long-term. *Loyola of Los Angeles Law Review*, 35: 277–291.
- Bokonon-Ganta A.H., de Groote H., and Neuenschwander P. 2002. Socio-economic impact of biological control of mango mealybug in Benin. *Agriculture, Ecosystems and Environment*, 93: 367–378.
- Byerlee D. and Heisey P.W. 1996. Past and potential impacts of maize research in sub-Saharan Africa: a critical assessment. *Food Policy*, 21(3): 255–277.
- Byerlee D. and Traxler G. 1995. National and international wheat improvement research in the post Green Revolution period: evolution and impact. *American Journal of Agricultural Economics*, 77: 268–278.
- Carter J. 1995. Alley farming: have resource-poor farmers benefited? *Natural Resources Perspective*, No. 3, June 1995. Overseas Development Institute: London, UK.
- CGIAR. 2004. CGIAR Financial Report 2003. Secretariat, Consultative Group on International Agricultural Research: Washington DC, USA.
- CGIAR. 2005. CGIAR Financial Report 2004. Secretariat, Consultative Group on International Agricultural Research: Washington DC, USA.
- CGIAR. Various years. CGIAR Annual Report. Washington DC: CGIAR Secretariat. <http://www.cgiar.org/publications/annual/index.html>.

- CGIAR. Various years. Financial Report. Washington DC: CGIAR Secretariat. <http://www.cgiar.org/publications/finrep/index.html>.
- Coulibaly O., Manyong V.M., Yaninek S., Hanna R., Sanginga P., Endamana D., Adesina A., Toko M., and Neuenschwander P. 2004. *Economic Impact Assessment of Classical Biological Control of Cassava Green Mite in West Africa*. International Institute of Tropical Agriculture: Cotonou, Benin.
- Dalton T.J. and Guei R.G. 2003. Ecological diversity and rice varietal improvement in West Africa. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- de Groote H., Ajuonua O., Attignona S., Djessoub R., and Neuenschwander P. 2003. Economic impact of biological control of water hyacinth in southern Benin. *Ecological Economics*, 45(1): 105–117.
- Deb U.K and Bantilan M.C.S. 2003. Impacts of genetic improvement in sorghum. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Dey M.M., Kambewa P., Prein M., Jamu D., Paraguas F.J., and Briones R.M. 2005. *Development and dissemination of integrated aquaculture-agriculture (IAA) technologies in Malawi*. Draft Paper Submitted to SPIA. WorldFish Center: Zomba, Malawi.
- Doss C.R., Mwangi W., Verkuil H., and de Groote H. 2003. *Adoption of Maize and Wheat Technologies in Eastern Africa: a Synthesis of the Findings of 22 Case Studies*. Centro Internacional de Mejoramiento de Maíz y Trigo: Mexico DF, Mexico.
- Eicher C.K. and Rukuni M. 2003. The CGIAR in Africa: past, present, and future. In: *The CGIAR at 31: An Independent Meta-Evaluation of the Consultative Group on International Agricultural Research*. World Bank: Washington DC, USA.
- Ekboir J., Boa K., and Dankyi A.A. 2002. *Impact of No-Till Technologies in Ghana*. Centro Internacional de Mejoramiento de Maíz y Trigo: Mexico DF, Mexico.
- Elbasha E., Thornton P.K., and Tarawali G. 1999. *An Ex Post Economic Assessment of Planted Forages in West Africa*. ILRI Impact Assessment. Series 2. International Livestock Research Institute: Nairobi, Kenya
- Evenson R.E. 2003. Production impacts of crop genetic improvement. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Evenson R.E. 2001. Economic impacts of agricultural research and extension. In Gardner B.L. and Rauser G.C. (Eds). *Handbook of Agricultural Economics*. Volume 1A. Elsevier: Amsterdam, The Netherlands
- Evenson R.E. and Gollin D. (Eds) 2003. *Crop Variety Improvement and its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Evenson R.E. and Rosegrant M. 2003. The economic consequences of CGI programs. In: *Crop Variety Improvement and its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Fall A. 2005. Impact économique de la recherche rizicole au Sénégal et au Mauritanie. *Agronomie Africaine*, 5: 53–62.
- Falusi A.O. and Afolami C.A. 1999. Effect of technology change and commercialization on income equity in Nigeria: the case of improved cassava. Paper presented at the CIAT workshop on Assessing the Impact of Agricultural Research on Poverty Alleviation. San Jose, Costa Rica, September 14–16, 1999. Centro Internacional de Agricultura Tropical: Cali, Colombia.
- Franzel S., Arimi H., and Murithi F. 2002. *Calliandra calothyrsus*: assessing the early stages of adoption of a fodder tree in the highlands of central Kenya. In: Franzel S. and Scherr S.J. (Eds). *Trees on the Farm: Assessing the Adoption Potential of Agroforestry Practices in Africa*. CAB International: Wallingford, UK.
- Franzel S. and Mwanda F. 2005. Estimating the numbers of farmers planting fodder shrubs in East Africa. Paper submitted to *Prunus Agroforestry Newsletter*. World Agroforestry Center: Nairobi, Kenya.

- Gardner B. 2003. Global public goods from the CGIAR: impact assessment. In: *The CGIAR at 31: An Independent Meta-Evaluation of the Consultative Group on International Agricultural Research*. World Bank: Washington DC, USA.
- Gryseels G. and Groenewold J.P. 2001. *Contributions made by the CGIAR and its Partners to Agricultural Development in Sub-Saharan Africa*. Food and Agriculture Organization of the United Nations: Rome, Italy.
- Heisey P.W., Lantican M.A., and Dubin H.J. 2002. *Impacts of International Wheat Breeding Research in Developing Countries, 1966–97*. Centro Internacional de Mejoramiento de Maíz y Trigo: Mexico DF, Mexico.
- Johnson N.L., Pachico D., and Wortmann C.S. 2003a. The impact of CIAT's genetic improvement research on beans. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and Its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Johnson, N.L., Pachico D., and Wortmann C.S. 2003b. The impact of IARC genetic improvement programmes on cassava. In: Evenson, R.E. and D. Gollin (Eds.) *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Kelley T. and Gregersen H. 2003. NRM impact assessment in the CGIAR: meeting the challenge and implications for ICRISAT. In: Shiferaw B., Freeman H.A., and Swinton S.M. (Eds). *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*. CAB International: Wallingford, UK.
- Lantican M.A., Dubin H.J., Morris M.L. 2005. *Impacts of International Wheat Breeding Research in the Developing World, 1988–2002*. Centro Internacional de Mejoramiento de Maíz y Trigo: Mexico DF, Mexico.
- Lele, U., Barrett C., Eicher C.K., Gardner B., Gerrard C., Kelly L., Lesser W., Perkins K., Rana S., Rukuni M., and Spielman D.J. 2003. *The CGIAR at 31: An Independent Meta-Evaluation of the Consultative Group on International Agricultural Research*. Operations Evaluation Department, World Bank: Washington DC, USA.
- Manyong V.M., Kling J.G., Makinde K.O., Ajala S.O., and Menkir A. 2003. *Impact of IITA Germplasm Improvement on Maize Production in West and Central Africa*. International Institute of Tropical Agriculture: Ibadan, Nigeria.
- Manyong V.M., Houndékon V.A., Sanginga P.C., Vissoh P., and Honlonkou A.N. 1999. *Mucuna fallow diffusion in southern Benin*. Impact series. International Institute of Tropical Agriculture: Ibadan, Nigeria.
- Maredia M., Byerlee D., and Anderson J.R. 2000. *Ex post* evaluation of economic impacts of agricultural research programs: a tour of good practice. In: *The Future of Impact Assessment in the CGIAR: Needs, Constraints and Options*. Food and Agriculture Organization of the United Nations: Rome, Italy.
- Maredia, M. and Byerlee D. 1996. *Measures of efficiency of wheat improvement research: A comparative analysis of national and international research systems in developing countries*. Paper presented at the International Conference on Global Agricultural Science Policy for the Twenty-First Century. Melbourne, Australia, 26–28 August, 1996. International Food Policy Research Institute: Washington DC, USA.
- Matlon P., Randolph T., and Guei R. 1996. Impact of rice research in West Africa. In: Prabhu L. and Pingali M.H. (Eds). *Impact of Rice Research*. International Rice Research Institute: Los Baños, the Philippines.
- Morris M.L., Mekuria M., and Gerpacio R. 2003. Impacts of CIMMYT maize breeding research. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and Its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.

- Norgaard R.B. 1988. The biological control of cassava mealybug in Africa. *American Journal of Agricultural Economics*, 70: 366–371.
- Pingali P.L. 2001. *Milestones in Impact Assessment Research in the CGIAR, 1970–1999*. Centro Internacional de Mejoramiento de Maíz y Trigo: Mexico DF, Mexico.
- Raitzer D.A. 2003. *Benefit–Cost Meta-Analysis of Investment in the International Agricultural Research Centers of the CGIAR*. Food and Agriculture Organization of the United Nations: Rome, Italy.
- Raitzer D.A. and Lindner R. 2005. *Review of the Returns to ACIAR’s Bilateral R&D Investments*. Impact Assessment Series 35. Australian Centre for International Agricultural Research: Canberra, Australia.
- Rohrbach D.D., Lechner W.R., Ipinge S.A., and Monyo E.S. 1999. *Impact from Investments in Crop Breeding: the case of Okashana 1 in Namibia*. Impact Series Number 4. International Crops Research Institute for the Semi-Arid Tropics: Patancheru, India.
- Rueda J.L., Ewell P.T., Walker T., Soto M., Bicamumpaka M., and Berrios D. 1996. Economic impact of high-yielding, late blight resistant varieties in the East and Central African highlands. In: Walker T. and Crissman C. (Eds). *Case Studies of the Economic Impact of CIP-Related Technologies*. Centro Internacional de la Papa: Lima, Peru.
- Rutherford A .S., Odero A.N., and Kruska R.L. 2001. *The Role of the Broadbed-Maker Plough In Ethiopian Farming Systems: An Ex Post Impact Assessment Study*. ILRI Impact Series Number 7. International Livestock Research Institute: Nairobi.
- Ryan J. 2002. *Synthesis Report of Workshop on Assessing the Impact of Policy-Oriented Social Science Research*. Scheveningen, The Netherlands, November 12–13, 2001. Impact Assessment Discussion Paper 15. International Food Policy Research Institute: Washington DC, USA.
- Salter A.J. and Martin B.R. 2001. The economic benefits of publicly funded basic research: a critical review. *Research Policy*, 30: 509–532.
- Schuh G.E. and Tollini H. 1978. *Costs and Benefits of Agricultural Research: State of the Art, and Implications for the CGIAR*. Consultative Group on International Agricultural Research Washington DC, USA
- Slavin R.E. 1995. Best evidence synthesis: an intelligent alternative to meta-analysis (review). *Journal of Clinical Epidemiology*, 48: 9–18.
- Tre J.P. 1995. The Rates of Return to Mangrove Rice Research in West Africa. Unpublished M.Sc. thesis. Purdue University: West Lafayette, Indiana, USA.
- Walker T.S., Bi Y.P., Li J.H., Gaur P.C., and Grande E. 2003. Potato genetic improvement in developing countries and CIP’s role in varietal change. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Yapi A.M., Debrah S.K., Dehala G., and Njomaha C. 1999. *Impact of Germplasm Research Spillovers: the Case of Sorghum Variety S35 in Cameroon and Chad*. Impact Series Number 3. International Crops Research Institute for the Semi-Arid Tropics: Patancheru, India.
- Zeddies J., Schaab R.P., Neuenschwander P., and Herren H.R. 2001. Economics of biological control of cassava mealybug in Africa. *Agricultural Economics*, 24: 209–219.

List of Studies Reviewed for Meta-Analysis

- Ahmed M.M., Masters W.A., and Sanders J.H. 1994. Returns to research in economies with policy distortions: hybrid sorghum in Sudan. *Agricultural Economics*, 12: 183–192.
- Ajayi O.C., Place F., Kwesiga F., and Mafongoya P. 2005. Fertilizer Trees, Their Development, Socio-Economic and Ecological Impacts in Southern Africa. Draft submitted to CGIAR Standing Panel on Impact Assessment. World Agroforestry Centre: Nairobi, Kenya.
- Anandajayasekeram P., Martella D.R., Sanders J., and Kupfurma B. 1995. *Report on the Impact Assessment of the SADC/ICRISAT Sorghum and Millet Improvement Program. Volumes I and II*. Southern African Development Cooperation: Gaborone, Botswana.
- Bokonon-Ganta A.H., de Groote H., and Neuenschwander P. 2002. Socio-economic impact of biological control of mango mealybug in Benin. *Agriculture, Ecosystems and Environment*, 93: 367–378.
- Byerlee D. and Traxler G. 1995. National and international wheat improvement research in the post Green Revolution period: evolution and impact. *American Journal of Agricultural Economics*, 77(2): 268–278.
- Coulibaly O., Manyong V.M., Yaninek S., Hanna R., Sanginga P., Endamana D., Adesina A., Toko M., and Neuenschwander P. 2004. *Economic Impact Assessment of Classical Biological Control of Cassava Green Mite in West Africa*. International Institute of Tropical Agriculture: Cotonou, Benin.
- Dalton T.J. and Guei R.G. 2003. Ecological diversity and rice varietal improvement in West Africa. In: Evenson, R.E. and Gollin D. (Eds), *Crop Variety Improvement and Its Effect on Productivity: the impact of international agricultural research*. CAB International: Wallingford, UK.
- de Groote H., Ajuonua O., Attignona S., Djessoub R., and Neuenschwander P. 2003. Economic impact of biological control of water hyacinth in Southern Benin. *Ecological Economics*, 45(1): 105–117.
- Dey M.M., Kambewa P., Prein M., Jamu D., Paraguas F.J., and Briones R.M. 2005. *Development and dissemination of integrated aquaculture-agriculture (IAA) technologies in Malawi*. Draft Paper Submitted to SPIA. WorldFish Center: Zomba, Malawi.
- Elbasha E., Thornton P.K., and Tarawali G. 1999. *An Ex post Economic Assessment of Planted Forages in West Africa*. ILRI Impact Assessment. Series 2. International Livestock Research Institute: Nairobi.
- Fall A. 2005. Impact economic de la Recherche Rizicole au Senegal et au Mauritanie. *Agronomie Africaine*, 5: 53–62.
- Heisey P.W., Lantican M.A., and Dubin H.J. 2002. *Impacts of International Wheat Breeding Research in Developing Countries, 1966–97*. Centro Internacional de Mejoramiento de Maíz y Trigo: Mexico, DF.
- Johnson N.L., Pachico D., and Wortmann C.S. 2003a. The impact of CIAT's genetic improvement research on beans. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and Its Effect on Productivity: the Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Johnson, N.L., Pachico D., and Wortmann C.S. 2003b. The impact of IARC genetic improvement programmes on cassava. In: Evenson, R.E. and D. Gollin (Eds.) *Crop Variety Improvement and Its Effect on Productivity: The Impact of International Agricultural Research*. CAB International: Wallingford, UK.
- Lantican M.A., Dubin H.J., and Morris M.L. 2005. *Impacts of International Wheat Breeding Research in the Developing World, 1988–2002*. Centro Internacional de Mejoramiento de Maíz y Trigo: Mexico DF, Mexico.

- Manyong V.M., Kling J.G., Makinde K.O., Ajala S.O., and Menkir A. 2003. *Impact of IITA Germplasm Improvement on Maize Production in West and Central Africa*. International Institute of Tropical Agriculture: Ibadan, Nigeria.
- Morris M.L., Mekuria M., and Gerpacio R. 2003. Impacts of CIMMYT maize breeding research. In: Evenson R.E. and Gollin D. (Eds). *Crop Variety Improvement and Its Effect on Productivity: the impact of international agricultural research*. CAB International: Wallingford, UK.
- Rohrbach D.D., Lechner W.R., Ipinge S.A., and Monyo E.S. 1999. *Impact from Investments in Crop Breeding: the Case of Okashana 1 in Namibia*. Impact Series Number 4. International Crops Research Institute for the Semi-Arid Tropics: Patancheru, India.
- Rueda J.L., Ewell P.T., Walker T., Soto M., Bicomumpaka M., and Berrios D. 1996. Economic impact of high-yielding, late blight resistant varieties in the East and Central African highlands. In: Walker T. and Crissman C. (Eds). *Case Studies of the Economic Impact of CIP-Related Technologies*. Centro Internacional de la Papa: Lima, Peru.
- Rutherford A.S., Odero A.N., and Kruska R.L. 2001. *The Role of the Broadbed-Maker Plough In Ethiopian Farming Systems: an Ex Post Impact Assessment Study*. ILRI Impact Series Number 7. International Livestock Research Institute: Nairobi.
- Tre J.P. 1995. The Rates of Return to Mangrove Rice Research in West Africa. Unpublished M.Sc. thesis. Purdue University: West Lafayette, Indiana, USA.
- Yapi A.M., Debrah S.K., Dehala G., and Njomaha C. 1999. *Impact of Germplasm Research Spillovers: the Case of Sorghum Variety S35 in Cameroon and Chad*. Impact Series Number 3. International Crops Research Institute for the Semi-Arid Tropics: Patancheru, India.
- Zeddies J., Schaab R.P., Neuenschwander P., and Herren H.R. 2001. Economics of biological control of cassava mealybug in Africa. *Agricultural Economics*, 24: 209–219.

Annex A

Bibliographic Information of Ex Post Impact Studies Included in the Database in Step 3

Studies are listed in alphabetical order by the author field

Study number	Authors	Year	Title	Crop/ animal/ policy	Technology	Involved CGIAR center ^a	Geographic coverage	Time period of reported analysis	Data used ^b	Methodology or approach	Study classification
1	Abass A.B., Onabolu A., and Bokanga M.	1998	Impact of the high-quality cassava flour technology in Nigeria	Cassava	Food processing	IITA	Nigeria	1996–98	Survey and interviews with commercial and non-commercial cassava flour producers	Adopter-level impacts based on survey responses	Farm-level impacts
2	Adesina A.A., Coulibaly O., Manyong V.M., Sanganga P.C., Mbila D., Chianu J., and Kamleu G.	1999	Policy shifts and adoption of alley farming in West and Central Africa	NA	Alley farming	IITA	West and Central Africa	1996	Survey	Adoption and impact study; logic analysis	Farm-level impacts
3	Ahmed M.M., Masters W.A., and Sanders J.H.	1994	Returns to research in economies with policy distortions: hybrid sorghum in Sudan	Sorghum	Improved variety	ICRISAT	Sudan	1979–92	Seed sales; farm-level data; secondary data	Partial equilibrium analysis; economic surplus	Aggregate impacts
4	Ajayi O.C., Place F., Kwesiga F. and Mafongoya P.	2005	Impact of NRM technologies on small-scale farmers: the case of fertilizer tree fallows in Zambia	NA	Fallow system	ICRAF	Zambia	1989–03	Primary data from farm plots	Benefit–cost analysis; environmental impacts	Aggregate impacts
5	Akoroda M.O., Gebremeskel, T., and Oyinlola A.E.	1989	Impact of IITA cassava varieties in Oyo State, Nigeria, 1976–1985	Cassava	Improved variety	IITA	Nigeria	1976–85	Farmer interviews; surveys; field trials	Adoption study; farm-level impact assessment	Farm-level impacts
6	Anandajayasakeram P. et al.	1995	Report on the impact assessment of the SADC/ICRISAT Sorghum and Millet Improvement Program	Sorghum/ millet	Improved variety	ICRISAT	Southern African Development Cooperation countries	1980–99	Field trials; secondary data	Economic surplus	Aggregate impacts
7	Bantian M.C.S. and Deb U.K.	2003	Impacts of genetic enhancement in pearl millet	Millet	Improved variety	ICRISAT	Sub-Saharan Africa	1986–98	Survey of companies; on-farm surveys; secondary data	Adoption study	Adoption
8	Bantian M.C.S., Deb U.K., and Nigam S.N.	2003	Impacts of genetic improvement in groundnut	Groundnut	Improved variety	ICRISAT	Southern Africa	1981–99	Impact monitoring surveys; secondary data	Documentation of adoption and some indicators of farm-level impacts	Adoption
9	Bokonon-Ganta A.H., de Groote H., and Neuenschwander P.	2002	Socioeconomic impact of biological control of mango mealybug in Benin	Mango	IPM--Biological control (mango mealybug)	IITA	Benin	1986–99	Farm surveys; secondary data	Benefit–cost analysis	Aggregate impacts

Annex A Bibliographic Information of Ex Post Impact Studies Included in the Database in Step 3 (continued)

Study number	Authors	Year	Title	Crop/ animal/ policy	Technology	Involved CGIAR center ^a	Geographic coverage	Time period of reported analysis	Data used ^b	Methodology or approach	Study classification
10	Byerlee D. and Traxler G.	1995	National and international wheat improvement research in the post-green revolution: evolution and impacts	Wheat	Improved variety	CIMMYT	Global	1977–90	Farm surveys; secondary data	Economic surplus	Aggregate impacts
11	Coulibaly O., Manyong V.M., Yaninek S., Hanna R., Sangina P., Endamana D., Adesina A., Toko M., and Neuenschwander P.	2004	Economic impact assessment of classical biological control of cassava green mite in West Africa	Cassava	IPM–biological control (green mite)	IITA	Benin, Ghana, Nigeria	1983–10	Experimental agronomic data; secondary data	Economic surplus	Aggregate impacts
12	Dalton T.J. and Guei R.G.	2003	Ecological diversity and rice variety improvement in West Africa	Rice	Improved variety	WARDA	Seven countries in West Africa	1998	Farm surveys; secondary data	GARB estimate for one year; Monte Carlo technique to derive probabilistic estimate of financial impact	Aggregate impacts
13	David S., Kirkby R., and Kasozi S.	2003	Impacts of the use of market and subsistence-oriented bean technology on poverty reduction in sub-Saharan Africa: evidence from Uganda	Bean	Improved variety	CIAT	Uganda	1998	Survey	Adoption study; farm-level impact assessment	Farm-level impacts
14	de Groote H., Ajuonua O., Attignona S., Djessoub R., and Neuenschwander P.	2003	Economic impact of biological control of water hyacinth in southern Benin	Fish	IPM–biological control of weed (water hyacinth)	IITA	Benin	1991–99	Household surveys; secondary data; informal surveys	Benefit–cost analysis based on household survey data	Aggregate impacts
15	Deb U.K. and Bantilan M.C.S.	2003	Impacts of genetic improvement in sorghum	Sorghum	Improved variety	ICRISAT	Sub-Saharan Africa	1971–95	Impact monitoring surveys; secondary data	Documentation of adoption and some indicators of farm-level impacts	Adoption
16	Deffo V., Njalelem D., Koi J., and Demo P.	2003	Socioeconomic impact of two potato varieties (Cipira and Tubira) released in Cameroon	Potato	Improved variety	CIP	Cameroon	1998	Impact survey	Analysis of survey data; estimates value of increased production	Farm-level impacts
17	Dey M.M., Kambewa P., Prein M., Jamu D., Paragwas F.J., Briones R.M.	2005	Development and dissemination of integrated aquaculture–agriculture (IAA) technologies in Malawi	NA	Integrated aquaculture–agriculture (IAA) technology	WorldFish	Malawi	1986–16	Survey and FAO FishStat	Economic surplus; Other social, economic and resource impact indicators reported	Aggregate impacts
18	Ekboir J., Boa K., and Dankyi A.A.	2002	Impact of no-till technologies in Ghana.	NA	No till	CIMMYT	Ghana	2000	Review paper	Adoption study	Farm-level impacts

Annex A Bibliographic Information of Ex Post Impact Studies Included in the Database in Step 3 (continued)

Study number	Authors	Year	Title	Crop/ animal/ policy	Technology	Involved CGIAR center ^a	Geographic coverage	Time period of reported analysis	Data used ^b	Methodology or approach	Study classification
19	Elbasha E., Thornton P.K., and Tarawali G.	1999	An ex post economic assessment of planted forages in West Africa	NA	Fodder bank	ILRI	Fifteen countries in West Africa	1978–97	Literature survey; primary data collection on adoption	Herd simulation model; economic surplus	Aggregate impacts
20	Eley R., Ibrahim H., Hambly H., Demeke M., and Smalley M.	2002	Evaluating the impact of the graduate fellowship program of the International Livestock Research Institute: a tools and process report	NA	Training	ILRI	Kenya and Ethiopia	1978–97	Survey	Training impacts	Adoption
21	Fall A.	2005	Impact économique de la Recherche Rizicole au Sénégal et au Mauritanie	Rice	Improved variety	WARDA	Senegal and Mauritania	1985–2000	Survey; field trials; secondary data	Economic surplus	Aggregate impacts
22	Falusi A.O., Afolami C.A.	1999	Effect of technology change and commercialization on income equity: the case of improved cassava	Cassava	Improved variety	IITA	Nigeria	1970–93	Past study results	Economic surplus	Aggregate impacts
23	Franzel S., Arim H., and Murithi F.	2002	<i>Calliandra calothyrsus</i> : assessing the early stages of adoption of a fodder tree in the highlands of central Kenya		Fodder shrub	ICRAF	Kenya	1991–00	Sample survey	Adoption study; value of production gain	Farm-level impacts
24	Hassan R.M., Mekuria M., and Mwangi W.M.	2001	Maize breeding research in Eastern and southern Africa: current status and impacts of past investments made by the public and private sectors, 1966–97	Maize	Improved variety	CIMMYT	Twelve countries in East and southern Africa	1966–97	Survey of breeding program; secondary seed sales	Adoption study	Adoption
25	Heisey P.W. and Lantican M.A.	2000	International wheat breeding research in eastern and southern Africa, 1966–97	Wheat	Improved variety	CIMMYT	Seven countries in East and southern Africa	1966–97	Review; survey of breeding programs; secondary data	Adoption study	Adoption
26	Heisey P.W., Lantican M.A., and Dubin H.J.	2002	Impacts of international wheat breeding research in developing countries, 1966–97	Wheat	Improved variety	CIMMYT	Global	1966–97	Survey and secondary data	Economic surplus	Aggregate impacts
27	Inaizumi H., Singh B.B., Sangina P.C., Manyong V.M., Adesina A.A., and Tarawali S.	1999	Adoption and impact of dry season dual-purpose cowpea in the semi-arid zone of Nigeria	Cowpea	Improved variety	IITA	Nigeria	1993–97	Farmer survey	Adoption study	Farm-level impacts

Annex A Bibliographic Information of Ex Post Impact Studies Included in the Database in Step 3 (continued)

Study number	Authors	Year	Title	Crop/ animal/ policy	Technology	Involved CGIAR center ^a	Geographic coverage	Time period of reported analysis	Data used ^b	Methodology or approach	Study classification
28	Johnson N.L., Pachico D., and Wortmann C.S.	2003	The Impact of IARC genetic improvement programs on cassava	Cassava	Improved variety	CIAT	Global	1981–97	Impact documentation by CIAT; secondary data	Adoption; value of increased production	Aggregate impacts
29	Johnson N.L., Pachico D., and Wortmann C.S.	2003	The impact of CIAT's genetic improvement research on beans	Beans	Improved variety	CIAT	Global	1966–98	Impact documentations by CIAT; secondary data	Adoption; value of increased production	Aggregate impacts
30	Kirkby R.A., David S., and Kasozi S.	1999	Assessing the impact of bush bean varieties poverty reduction in sub-Saharan Africa: evidence from Uganda	Beans	Improved variety	CIAT	Uganda	1995–99	Survey, literature review; secondary data	Adoption study	Farm-level impacts
31	Kristjansson P., Okike I., Tarawali S.A., Kruska R., Manyong V.M., and Singh B.B.	2002	Evaluating adoption of new crop-livestock-soil-management technologies using georeferenced village-level data: the case of cowpea in the dry savannas of West Africa	Cowpea	Improved variety in a livestock system for NRM	IITA/ILRI	Nigeria	1999–00	Village level surveys; farmer interviews; focus groups	Georeferencing; adoption study; Tobit analysis	Adoption
32	Lantican M.A., Dubin H.J., and Morris M.L.	2005	Impacts of international wheat breeding research in the developing world: 1988–2002	Wheat	Improved variety	CIMMYT	Global	1988–02	Survey and secondary data	Adoption study; benefit-cost analysis	Aggregate impacts
33	Manyong V.M., Kling J.G., Makinde K.O., Ajala S.O., and Menkir A.	2003	Impact of IITA germplasm improvement on maize production in West and Central Africa	Maize	Improved variety	IITA	Eleven countries in West and Central Africa	1965–98	Survey of maize breeding program leaders; expert opinion; secondary data	Adoption study; valuation of increased production; training impacts	Aggregate impacts
34	Monyo E.S., Mgonja M.A., Ngeresa J.A., and Rohrbach D.D.	2002	Adoption of improved sorghum and pearl millet varieties in Tanzania	Sorghum/ Millet	Improved variety	ICRISAT	Tanzania	2001	Survey	Adoption study	Adoption
35	Morris M.L., Tripp R., Dankyi A.A.	1999	Adoption and impacts of improved maize production technology: a case study of the Ghana Grains Development Project	Maize	Improved variety	CIMMYT/ IITA	Ghana	1979–97	National survey of maize growers	Adoption study	Farm-level impacts
36	Morris M.L., Mekuria M., and Gerpacio R.	2003	Impacts of CIMMYT maize breeding research	Maize	Improved variety	CIMMYT	Global	1966–98	Survey of public and private breeding programs; secondary data	Adoption study; benefit-cost analysis	Aggregate impacts

Annex A Bibliographic Information of Ex Post Impact Studies Included in the Database in Step 3 (continued)

Study number	Authors	Year	Title	Crop/animal/policy	Technology	Involved CGIAR center ^a	Geographic coverage	Time period of reported analysis	Data used ^b	Methodology or approach	Study classification
37	Ndjeunga J. and Bantilan M.S.C.	2002	Uptake of improved technologies in the semi-arid tropics of West Africa: why is agricultural transformation lagging behind?	Sorghum/ Millet	Improved variety	ICRISAT	Mali, Burkina Faso and Niger	2000–01	Survey	Adoption/review paper	Adoption
38	Nicholson C.F., Thornton P.K., Mohamed L., Muinga R.F., Mwamachi D.M., Elbasha E.H., Staal S.J., and Thorpe W.	1999	Smallholder dairy technology in coastal Kenya: an adoption and impact study	NA	Improved animal, fodder crop, and animal disease treatment method	ILRI	Kenya	1997–98	Household survey	Survey data analysis and econometric analysis	Farm-level impacts
39	Odendo M. and Ndolo P.J.	2002	Impact of improved sweet potato varieties in western Kenya: farmers' perspectives	Sweet potato	Improved variety	CIP	Kenya	1994–01	Household survey; literature review; expert opinion	Survey data analysis	Farm-level impacts
40	Place F., Adato M., Hebinck P., and Omosa M.	2003	The impact of agroforestry-based soil fertility replenishment practices on the poor in western Kenya	NA	Soil fertility replenishment practices	ICRAF	Kenya	1997–00	Survey; focus group discussions; case studies	Adoption and impact study	Farm-level impacts
41	Place F., Franzel S., Noordin Q., and Jama B.	2003	Improved fallows in Kenya: history, farmer practice, and impacts	NA	Improved fallow	ICRAF	Kenya	1996–01	Survey and case studies	Adoption study	Farm-level impacts
42	Rohrbach D.D., Lechner W.R., Ipinge S.A., and Monyo E.S.	1999	Impact from investments in crop breeding: the case of Okashana I in Namibia	Pearl millet	Improved variety	ICRISAT	Namibia	1986–98	Farm survey; seed sales; trial data	Economic surplus	Aggregate impacts
43	Rueda J.L., Ewell P.T., Walker T., Soto M., Bicamumpaka M., and Berrios D.	1996	Economic impact of high-yielding, late blight resistant varieties in the East and Central African Highlands	Potato	Improved variety	CIP	Burundi, Rwanda, and Democratic Republic of Congo	1978–93	Impact survey	Analysis of survey data (adoption and benefits) and benefit-cost analysis	Aggregate impacts
44	Rutherford A.S., Odero A. N., and Kruska R.L.	2001	The role of the broadbedmaker-plough in Ethiopian farming systems: an <i>ex post</i> impact assessment study	NA	Farm machinery—broadbed-maker plough	ILRI	Ethiopia	1986–98	GIS and farm survey	Economic surplus	Aggregate impacts
45	Ryan J.G.	1999	Assessing the impact of policy research and capacity building by IFPRI in Malawi	Policy	Policy recommendations	IFPRI	Malawi	1999	Interviews with donors; collaborator; students	Impact of policy research	Adoption

Annex A Bibliographic Information of Ex Post Impact Studies Included in the Database in Step 3 (continued)

Study number	Authors	Year	Title	Crop/animal/policy	Technology	Involved CGIAR center ^a	Geographic coverage	Time period of reported analysis	Data used ^b	Methodology or approach	Study classification
46	Sanginga P.C., Adesina A.A., Manyong V.M., Orite O., and Dashiell K.E.	1999	Social impact of soybean in Nigeria's southern Guinea savanna	Soybean	Improved variety	IITA	Nigeria	1998	Household survey; secondary data	Social impact assessment	Farm-level impacts
47	Sperling L., Munyaneza S.	1995	Intensifying production among smallholder farmers: the impact of improved climbing beans in Rwanda	Beans	Improved variety	CIAT	Rwanda	1992–93	Survey	Adoption study and farm level impacts	Farm-level impacts
48	Tesfaye A., Giorgis G.M.W., Gebre E., and Lembaga B	2003	Adoption and impact assessment of potato production technologies in central parts of Ethiopia	Potato	Improved variety with other inputs	CIP	Ethiopia	Early 1990s–2002	Household survey	Adoption study and valuation of farm-level impacts	Farm-level impacts
49	Tiré J.P.	1995	The rates of return to mangrove rice research in West Africa	Rice	Improved variety	WARDA	Sierra Leone and other West African countries	1976–2010	Farmer survey; secondary data	Economic surplus	Aggregate impacts
50	Walker T.S., Bi Y.P., Li J.H., Gaur P.C., Grande E.	2003	Potato genetic improvement in developing countries and CIP's role in varietal change	Potato	Improved variety	CIP	Global	1972–21	Past survey; secondary data	Global scale adoption study and back of the envelope estimates of rate of return on investment of CIP	Adoption
51	Yapi A.M., Debrah S.K., and Dehala G. Njomah C.	1999	Impact of germplasm research spillovers: the case of sorghum variety S35 in Cameroon and Chad	Sorghum	Improved variety	ICRISAT	Cameroon and Chad	1982–18	Survey; yield trials; secondary data	Economic surplus	Aggregate impacts
52	Zeddies J., Schaab R.P., Neuenschwander P., and Herren H.R.	2001	Economics of biological control of cassava mealybug in Africa	Cassava	IPM – biological control (green mite)	IITA	Twenty-seven countries in sub-Saharan Africa	1974–13	Past documented impacts; experimental data; survey for crop loss; secondary data	Benefit–cost analysis under four scenarios	Aggregate impacts

^a For an explanation of acronyms see acronym list, page viii

^b FAO = Food and Agriculture Organization of the United Nations

Annex B

Review and Adoption Studies Included in the Database in Step 3

Studies are listed in alphabetical order by the author field.

Number	Author	Year	Title	Crop	Technology	CGIAR center leading the research	Major results/findings reported
1	Ahmed M.M., Sanders J.H., and Neil W.T.	2000	New sorghum and millet cultivar: introduction in sub-Saharan Africa: impacts and research agenda	Sorghum/ millet	Improved variety	ICRISAT	In spite of substantial introduction of new sorghum and millet cultivars in semi-arid sub-Saharan Africa, there has been minimum aggregate impact on yields in contrast with other crops. Only where inorganic fertilizers and improved water retention or irrigation were combined with new cultivars were there large yield increases. Given the low soil fertility and irregular rainfall in semi-arid regions, both increased water availability and higher levels of principal nutrients will apparently be necessary for substantial yield increase. The cultivar-alone strategy is unlikely to have a significant sustainable yield effect and therefore reduce poverty in semi-arid sub-Saharan Africa
2	Ajayi O.C., Franzel S., Kuntashula E., and Kwesiga F.	2003	Adoption of improved fallow technology for soil fertility management in Zambia: empirical studies and emerging issues	Trees	Improved fallow	ICRAF	Adoption of improved fallows is not a binary choice problem but a process along a continuum in the adoption path. Further, adoption of improved fallows may not take place in a policy vacuum but needs to be facilitated by appropriate and conducive policy and institutional incentives
3	Alene A.D., Neuenchwander P., Manyong V.M., Coulbaly O., and R. Hanna	2005	The impact of IITA-led biological control of major pests in sub-Saharan African agriculture: a synthesis of milestones and empirical results	Cassava, mango, and fish	Biological control	IITA	Results of the few economic impact studies conducted reveal high benefits of biological control. They show that classical biological control is a cost-effective and sustainable option to lower economic and environmental losses due to pests. The benefits were achieved using innovative approaches to scaling-up environmentally friendly technologies through a wide partnership of institutions across continents and by building up the capacity of national programs
4	Byerlee D. and Heisey P.W.	1996	Past and potential impacts of maize research in sub-Saharan Africa: a critical assessment	Maize	Improved variety and crop management technology	CIMMYT	As a result of the rapid adoption of improved maize varieties and hybrids in the 1980s, 33–50% of the maize area in mid-1990s is reportedly sown to improved maize germplasm. In countries where research programs have not been able to ensure continuity of staff and breeding strategies, agricultural research has had less impact. The number of varietal releases per million hectares of maize and the adoption of improved maize varieties and hybrids are similar to the rates achieved in other regions. Nonetheless, adoption of improved maize materials has remained patchy. The use of modern varieties of maize has been accompanied by increased use of external inputs, especially fertilizer

Annex B Review and Adoption Studies Included in the Database in Step 3 (continued)

Number	Author	Year	Title	Crop	Technology	CGIAR center leading the research	Major results/findings reported
5	Doss C. R., Mwangi W., Verkuil H., and de Groote H.	2003	Adoption of maize and wheat technologies in eastern Africa: a synthesis of the findings of 22 case studies	Maize and wheat	Improved variety	CIMMYT	This paper synthesizes the findings of 22 micro-level studies on technology adoption carried out by CIMMYT with NARS in Ethiopia, Kenya, Tanzania, and Uganda during 1996–1999. The authors found that technology adoption is taking place across eastern Africa but considerable scope remains to improve the productivity of smallholder agriculture in higher potential regions with high levels of adoption. Extension was the variable most highly correlated with technology adoption. Future adoption studies can be improved by standardizing definitions across studies and using sampling techniques that allow results to be generalized across wider areas. Finally, the paper suggests that maize and wheat breeding research should be made more relevant to the preferences and circumstances of farmers, that the link between research and extension should be strengthened and include the private sector and NGOs, that policies should support the development and expansion of efficient markets for inputs and outputs, and that rural credit systems should be strengthened
6	Doss C.R.	2003	Understanding farm-level technology adoption: lessons learned from CIMMYT's micro surveys in eastern Africa	Maize, wheat	Improved variety	CIMMYT	During 1996–1998, CIMMYT collaborated with NARS in four countries in eastern Africa to conduct 22 micro-level studies on the adoption of improved varieties of wheat and maize and of chemical fertilizers. One of the goals was to increase the information available on technology adoption in eastern Africa. This paper explores the extent to which this goal was (and could be) met. Recommendations include the use of sampling approaches that allow data from micro-level studies to be generalized to higher levels of aggregation, adhering to standard formats and definitions of terms across studies, documenting and storing data in ways that facilitate their widespread use, and carefully examining assumptions that often underlie such studies (especially the assumption that an 'improved technology' is always better than existing technologies)
7	Douthwaite B., Manyong V.M., Keatinge J.D.H., and Chianu J.	2002	The adoption of alley farming and <i>Mucuna</i> : lessons for research, development, and extension	Alley farming and <i>Mucuna</i>	NRM	IITA/ILRI	This paper evaluates the utility of the 'learning selection' model of the early adoption process, to explain farmers' adoption and rejection of two soil-improving technologies - alley farming and the use of <i>Mucuna</i> cover crops. The analyses show that <i>Mucuna</i> was more successful than alley farming for four reasons: (1) early research and extension took farmers' perceptions into account when changing from recommending <i>Mucuna</i> for soil improvement to weed suppression; (2) it was then introduced into areas where there was a real need for the technology; (3) it gave short-term benefits; and (4) it was more amenable to farmer modification and adaptation. The paper also used the learning selection model to derive research and extension guidelines. The close match between these guidelines and the literature suggests that a constructivist perspective in general, and the learning selection model in particular, can provide a useful road map to planning and carrying out research and extension
8	Evenson R.E.	2003	Production impacts of crop germplasm improvement	CGIAR mandated crops	Improved variety	CGIAR	This chapter provides a summary of adoption of improved varieties by crops and regions, estimates yield contributions due to CGI research, and partitions these by attribution to CGIAR and NARS efforts. The annex reports IRR and BCR investments in CGI by regions, including SSA. Methodology for deriving these estimates is not very transparent

Annex B Review and Adoption Studies Included in the Database in Step 3 (continued)

CGIAR center leading the research							Major results/findings reported
Number	Author	Year	Title	Crop	Technology		
9	Tarawali G., Manyong V.M., Carsky R.J., Vissoh P.V., Osei-Bonsu P., and Galiba M.	1999	Adoption of improved fallows in West Africa: lessons from <i>Mucuna</i> and stylo case studies	Fallow // <i>Mucuna</i> and stylo	NRM	IITA	This paper reviews how velvet bean (<i>Mucuna pruriens</i>) and stylo (<i>Stylosanthes hamata</i> and <i>Stylosanthes guianensis</i>) management systems were developed and disseminated in West Africa. The uptake of stylo has been relatively slow and modest in West Africa in contrast to the faster rate of adoption of <i>Mucuna</i> in south-western Benin. Some of the contributory factors to the slower adoption of stylo include rainfall pattern, lack of motivation of livestock keepers, insecure land tenure, limited capability and facilities of extension staff, poor communication among scientists, and unsatisfactory establishment of the crop. Recommendations to increase the adoption of improved fallows include the use of a participatory approach in problem identification, expansion of the genetic base of cover crops for use in fallows, optimization of the multiple benefits of cover crops, management of the improved system, promotional strategies, and appropriate policies
10	Matlon P., Randolph T., and Guei R.	1996	Impact of rice research in West Africa	Rice	Improved variety	WARDA	Following a brief description of the West African rice sector, this chapter provides a historical overview of the mechanisms through which exotic rice germplasm has been introduced and tested in Africa. The evolution of applied breeding programs in the sub-region is also reviewed. An examination of the status of rice technology adoption and impact studies in West Africa is also provided. It is contended that limited evidence is available on varietal adoption in distinct rice growing ecosystems, and an analysis is carried out to identify the major adoption patterns, determinants and constraints on the rice sector. The chapter concludes with an assessment of current research directions, the prospects for accelerated progress in rice improvement research, and the need for further research on adoption and impacts
11	Place, F., Franzel S., de Wolf J., Rommelse R., Kwesiga F., Niang A., and Jama B.	2002	Agroforestry for soil fertility replenishment: evidence on adoption processes in Kenya and Zambia	Trees	Soil fertility replenishment practices	World Agroforestry	Improved fallow and biomass transfer systems are feasible and acceptable to farmers, at least at the modest levels with which they are initially being used. Economic analyses have also found the systems to be profitable to farmers. Both male and female farmers use these systems. Additionally, the percentage of poor households using these agroforestry systems exceed that of other soil fertility options. Thus, there are positive signs that the agroforestry options may be useful for disadvantaged groups in rural Africa. But there remain difficulties in reaching the very poor or near-landless with agricultural technologies. Whether agroforestry systems can indeed catalyze or contribute to processes to alleviate poverty and, if so, whether these systems can be effectively disseminated to resource-poor farmers are critical remaining areas for research and development

Annex C

Rate of Return Studies Included in the Alston et al. (2000) Study: Characteristics and Comparison with the Studies Included in the Present Report

Study number	Year published	First author	Research performer	Location of research performer	Commodity	Rate of return type	No. of rate of return observations reported	No. of observations included in Alston et al. meta-analysis	Minimum IRR	Maximum IRR	Included in this study's meta-analysis?	Reason for not including
1	1975	Evenson R.	Government	South Africa	Sugarcane	Research	2	2	29	40	No	Not a CGIAR-mandated crop
2	1978	Abidogun A.	Government	Nigeria	Cocoa	Both	2	2	34	37	No	Not a CGIAR-mandated crop
3	1988	Norgaard R.	International/ Government	Africa	Cassava	Research	1	1	1490	1490	No	A latter study by Zeddies et al. was included
4	1989	Schwartz L.	Government	Senegal	Cowpea	Both	1	1	63	63	No	Assessment of NARS and donor-funded efforts
5	1990	Karanja D.	Government	Kenya	Maize	Research	1	1	68.1	68.1	No	Assessment of aggregate NARS efforts
5	1990	Karanja D.	Government	Kenya	Maize	Research	1	1	40.9	40.9	No	Assessment of aggregate NARS efforts
6	1991	Mazzucato V.	Government	Kenya	Maize	Research	2	2	58	60	No	Assessment of aggregate NARS efforts
7	1992	McMillan J.	Other	Zimbabwe	Maize	Extension	1	1	22	22	No	Assessment of extension efforts
8	1992a	Thirtle C.	Government	Zimbabwe	All agriculture	Both	1	1	54	54	No	Assessment of aggregate NARS efforts
9	1993	Ahmed M.	Other	Sudan	Sorghum	Both	9	9	13.15	33.7	Yes	
10	1993	Howard J.	Government	Zambia	Maize	Both	4	4	-100	102.1	No	Assessment of aggregate NARS efforts
10	1993	Howard J.	Government	Zambia	Maize	Both	4	4	-100	106.2	No	Assessment of aggregate NARS efforts
10	1993	Howard J.	Government	Zambia	Maize	Research	2	2	96.9	106.2	No	Assessment of aggregate NARS efforts
10	1993	Howard J.	Government	Zambia	Maize	Research	2	2	103	110.3	No	Assessment of aggregate NARS efforts
11	1993	Mazzucato V.	Government	Niger	Other crops	Both	1	1	10	10	No	Assessment of aggregate NARS efforts
12	1993	Schwartz L.	Government	Senegal	Cowpeas	Both	3	3	31	92	No	Assessment of NARS and donor-funded efforts
13	1993a	Bindlish V.	Government	Burkina Faso	All crops	Extension	4	4	86	136	No	Assessment of extension efforts

Annex C Rate of Return Studies Included in the Alston et al. (2000) Study: Characteristics and Comparison with the Studies Included in the Present Report (continued)

Study number	Year published	First author	Research performer	Location of research performer	Commodity	Rate of return type	No. of rate of return observations reported	No. of observations included in Alston et al. meta-analysis	Minimum IRR	Maximum IRR	Included in this study's meta-analysis?	Reason for not including
14	1993a	Thirtle C.	Government	Zimbabwe	All agriculture	Both	1	1	43	43	No	Assessment of aggregate NARS efforts
15	1993b	Bindlish V.	Government	Kenya	All crops	Extension	2		52	350	No	Assessment of extension efforts
16	1993b	Thirtle C.	Government	South Africa	All agriculture	Both	1	1	145	145	No	Assessment of aggregate NARS efforts
16	1993b	Thirtle C.	Government	South Africa	All agriculture	Research	2	2	128	135	No	Assessment of aggregate NARS efforts
17	1994	Boughton D.	Government	Mali	Maize	Both	10	10	38	135	No	Assessment of aggregate NARS efforts
18	1994	Byerlee D.	International/ Government	Africa	Wheat	Research	1	1	25	25	No	A latter study (1995) by the same author is included instead
19	1994	Howard J.	Government	Zambia	Maize	both	1		<0	<0	No	Assessment of aggregate NARS efforts
19	1994	Howard J.	Government	Zambia	Maize	both	1		<0	<0	No	Assessment of aggregate NARS efforts
19	1994	Howard J.	Government	Zambia	Maize	both	3	3	42.1	105.8	No	Assessment of aggregate NARS efforts
19	1994	Howard J.	Government	Zambia	Maize	both	1	1	49.3	49.3	No	Assessment of aggregate NARS efforts
19	1994	Howard J.	Government	Zambia	Maize	Research	2	2	113.9	116.6	No	Assessment of aggregate NARS efforts
20	1994	Kupfuma B.	Government	Zimbabwe	Maize	both	4	4	43.5	46.5	No	Assessment of aggregate NARS efforts
21	1994	Sanders J.	Government	Ghana	Maize	both	1	1	74	74	No	Assessment of NARS and donor-funded efforts
22	1994	Smale M.	Government	Malawi	Maize	Research	4	4	4	63	No	Assessment of aggregate NARS efforts
23	1994	Sterns J.	Government	Cameroon	Cowpea	both	2	2	11.4	15.5	No	Assessment of NARS and donor-funded efforts
23	1994	Sterns J.	Government	Cameroon	Sorghum	both	2	2	-2.3	0.9	No	A latter study by Yapi et al. (1999) is included instead
23	1994	Sterns J.	Government	Cameroon	Sorghum	Research	1	1	7.7	7.7	No	A latter study by Yapi et al. (1999) is included instead
24	1994a	Laker-Ojok R.	Government	Uganda	Groundnut	both	5	5	-3.4	37.1	No	Assessment of aggregate NARS efforts

Annex C Rate of Return Studies Included in the Alston et al. (2000) Study: Characteristics and Comparison with the Studies Included in the Present Report
(continued)

Study number	Year published	First author	Research performer	Location of research performer	Commodity	Rate of return type	No. of rate observations reported	No. of observations included in Alston et al. meta-analysis	Minimum IRR	Maximum IRR	Included in this study's meta-analysis?	Reason for not including
24	1994a	Laker-Ojok R.	Government	Uganda	Sesame	Both	6	6	-12.3	43.6	No	Not a CGIAR-led research project
24	1994a	Laker-Ojok R.	Government	Uganda	Groundnut	Research	4	4	14.3	44.4	No	Assessment of aggregate NARS efforts
24	1994a	Laker-Ojok R.	Government	Uganda	Sesame	Research	4	4	22.1	49	No	Not a CGIAR-led research project
25	1994b	Laker-Ojok R.	Government	Uganda	Maize	Both	3	3	-56.6	35.6	No	Assessment of aggregate NARS efforts
25	1994b	Laker-Ojok R.	Government	Uganda	Maize	Both	6	6	-33.4	33.2	No	Assessment of aggregate NARS efforts
25	1994b	Laker-Ojok R.	Government	Uganda	Other crops	Both	6	6	-14.3	35.8	No	Assessment of aggregate NARS efforts
25	1994b	Laker-Ojok R.	Government	Uganda	Maize	Research	3	3	-6.9	35.1	No	Assessment of aggregate NARS efforts
25	1994b	Laker-Ojok R.	Government	Uganda	Other crops	Research	2	2	-7.4	3.2	No	Assessment of aggregate NARS efforts
26	1995	Anandajayasekaram P.	Government	Namibia	Millet	Both	4	4	4.25	20.13	No	A latter study by Rohrbach et al. (1999) on the same technology and country is included instead
26	1995	Anandajayasekaram P.	Government	Zimbabwe	Sorghum	Both	8	8	21.8	27.6	Yes	
27	1995	Byerlee D.	International/ Government	Africa	Wheat	Research	1	1	23	23	Yes	
28	1995	Ouedraogo S.	Government	Burkina Faso	Maize	Both	1	1	78.1	78.1	No	Study not readily accessible for review
29	1995	Seck P.	Government	Senegal	Cotton	Both	3	3	32.9	37	No	Not a CGIAR-led research project
30	1995	Tre J.	International/ Government	Sierra Leone	Rice	Research	4	4	17.92	21.4	Yes	
31	1996	Aghib A.	Government	Niger	Sorghum	Both	6	6	45	66.4	No	Assessment of a World Vision International project
32	1996	Alkungor S.	Government	Kenya	Wheat	Research	1	1	14	14	No	Assessment of aggregate NARS efforts
33	1996	Arnade	University/ Government	South Africa	All agriculture	Research	1	1	170	170	No	Not a CGIAR-led research project
33	1996	Arnade	University/ Government	South Africa	All agriculture	Research	2	2	44	58	No	Not a CGIAR-led research project
34	1996	Chisi M.	Government	Zambia	Sorghum	Both	17	17	10.22	25.18	No	Study not readily accessible for review

Annex C Rate of Return Studies Included in the Alston et al. (2000) Study: Characteristics and Comparison with the Studies Included in the Present Report
(continued)

Study number	Year published	First author	Research performer	Location of research performer	Commodity	Rate of return type	No. of return observations reported	No. of observations included in Alston et al. meta-analysis	Minimum IRR	Maximum IRR	Included in this study's meta-analysis?	Reason for not including
35	1996	Howard J.	Government	Zambia	Maize	Both	1		<0	<0	No	Assessment of aggregate NARS efforts
35	1996	Howard J.	Government	Zambia	Maize	Both	7	7	42.1	96	No	Assessment of aggregate NARS efforts
36	1996	Karanja D.	Government	Kenya	Maize	Research	4	4	39	60.8	No	Assessment of aggregate NARS efforts
37	1996	Njomaha C.	Government	Cameroon	Sorghum	Both	9	9	10.9	122.5	No	A latter study by Yapi et al. (1999) is included instead
38	1996	Ouedraogo S.	Government	Burkina Faso	Other crops	Extension	1		7	7	No	Assessment of extension efforts
39	1996	Rueda J.	Government	Rwanda/Burundi	Potato	Both	1	1	84	84	Yes	
40	1996	Yallah N.	Government	Chad	Cotton	Both	1	1	188	188	No	Not a CGIAR-led research project
41	1996	Yapi A.	International	Mali	Millet	Both	1	1	69.98	69.98	Yes	
41	1996	Yapi A.	International	Mali	Sorghum	Both	1	1	50	50	Yes	
42	1996a	Khatri Y.	Government	South Africa	Crops and livestock	Research	1	1	44.25	44.25	No	Assessment of aggregate NARS efforts
43	1997	Berlin R.	Government	Mali	Millet	Both	2	2	30.61	37.64	No	Study not readily accessible for review
44	1997	Bindlish V.	Government	Kenya	All crops	Extension	1		>100	>100	No	Assessment of extension efforts
44	1997	Bindlish V.	Government	Kenya	All crops	Extension	1		28	28	No	Assessment of extension efforts
45	1997	Edwin J.	Government	Sierra Leone	Rice	Research	1	1	34.1	34.1	No	Study not readily accessible for review
46	1997	Ouedraogo S.	Government	Burkina Faso	Other crops	Both	1	1	52.71	52.71	No	Assessment of aggregate NARS efforts
47	1997	Seidi S.	Government	Guinea Bissau	Rice	Both	1	1	26	26	No	Previous comprehensive study by Tre (1995) included in the analysis
TOTAL OBSERVATIONS							201	188				

Source: Appendix, Alston et al. (2000). For complete citation of the listed studies, see References to Appendix in Alston et al. (2000)

Annex D

Results of the Critical Review of 23 Impact Studies: Average Scores for Transparency and Analytical Rigor, and Implications for the Meta-Analysis

Study number ^a	Study	Transparency											Analytical rigor							Average score		Classification for meta-analysis	
		Explicitness of key assumptions	Substantiation of key assumptions	Citation of adoption data	Citation of productivity data	Citation of adoption-related costs	Citation of price sources	Explanation of scaling up: adoption estimates	Explanation of scaling up: productivity estimates	Explanation of scaling up: adoption related costs	Explanation of economic valuation	Explanation of counterfactual derivation	Reliability of data set utilized	Comprehensiveness of data set utilized	Appropriateness of data extrapolation	Adequacy of analysis of mitigating factors	Adequacy of capturing variability in target environments	Adequacy of disaggregation of CS benefits/surplus by CS and PS	Counterfactual plausibility	Transparency	Analytical rigor		
3	Ahmed et al. (1994)	2.5	2.5	1.8	2.0	1.5	3.0	2.0	1.8	1.5	3.0	2.0	2.0	2.0	2.5	3.0	0.5	0.5	0.5	2.3	2.1	1.8	Substantially demonstrated
4	Ajayi et al. (2005)	2.5	2.3	1.5	1.8	2.3	1.8	1.3	1.3	1.8	0.8	1.5	1.3	1.0	0.5	0.5	0.0	0.0	2.0	1.7	0.8	Potential	
6	Anandajayasekeram et al. (1995)	3.0	3.0	2.5	2.3	2.3	2.8	2.5	2.3	3.0	3.0	2.3	2.5	1.8	2.0	0.5	0.0	0.0	2.0	2.6	1.3	Plausible	
9	Bokonon-Ganta et al. (2002)	2.5	2.0	NA	2.8	2.0	2.0	1.0	1.5	NA	2.3	2.5	1.8	2.0	2.0	1.8	2.3	0.0	2.0	2.1	1.7	Substantially demonstrated	
10	Byerlee and Traxler (1995)	2.8	3.0	3.0	2.5	1.0	3.0	2.5	2.0	1.0	3.0	1.3	2.8	2.5	2.8	2.3	2.8	0.5	2.0	2.3	2.2	Substantially demonstrated	
11	Coulibaly et al. (2004)	1.5	0.5	NA	1.0	0.5	0.0	NA	0.0	NA	1.5	0.3	0.5	0.5	0.5	0.3	0.0	3.5	0.8	0.7	0.9	Potential	
12	Dalton and Guei (2003)	2.0	2.0	2.0	0.5	1.0	3.0	1.5	0.5	0.5	2.0	1.5	1.3	1.3	2.0	0.0	2.0	0.0	1.0	1.5	1.1	Plausible	
14	de Groote et al. (2003)	2.5	1.8	NA	2.5	NA	1.0	NA	1.8	NA	2.3	1.8	1.3	1.5	0.8	0.8	1.5	0.0	1.5	1.9	1.04	Plausible	
17	Dey et al. (2005)	2.5	2.3	0.5	1.5	1.0	0.5	0.5	1.5	0.0	1.8	1.8	2.3	1.5	1.0	1.0	1.8	1.3	2.5	1.3	1.6	Potential	
19	Elbasha et al. (1999)	3.0	2.8	2.0	2.3	2.5	2.0	2.5	2.0	1.8	1.5	1.0	1.8	2.3	2.5	0.8	2.0	3.0	2.0	2.1	2.0	Substantially demonstrated	
21	Fall (2005)	2.0	2.0	1.5	1.0	1.0	1.5	1.5	1.0	1.0	2.0	1.5	1.0	1.5	2.0	1.0	1.5	1.0	2.0	1.5	1.4	Plausible	
26	Heisey et al. (2002)	3.0	2.5	2.5	2.5	1.0	2.5	2.8	2.5	1.3	2.5	1.5	2.3	2.0	1.8	1.8	0.3	0.0	2.0	2.2	1.4	Plausible	

Annex D Results of the Critical Review of 23 Impact Studies: Average Scores for Transparency and Analytical Rigor, and Implications for the Meta-Analysis (continued)

Study number ^a	Study	Transparency										Analytical rigor							Average score		Classification for meta-analysis		
		Explicitness of key assumptions	Substantiation of key assumptions	Citation of adoption data	Citation of productivity data	Citation of adoption-related costs	Citation of price sources	Explanation of scaling up: adoption estimates	Explanation of scaling up: productivity estimates	Explanation of scaling up: adoption related costs	Explanation of economic valuation	Explanation of counterfactual derivation	Reliability of data set utilized	Comprehensiveness of data set utilized	Appropriateness of data extrapolation	Adequacy of analysis of mitigating factors	Adequacy of capturing variability in target environments	Adequacy of disaggregation of CS and PS benefits/surplus by CS	Counterfactual plausibility	Transparency		Analytical rigor	
28	Johnson et al. (2003a)	3.0	2.5	3.0	2.5	1.0	0.5	1.0	1.0	1.0	0.5	1.5	1.8	1.3	0.0	1.0	1.0	0.0	1.8	1.5	1.0	1.0	Plausible
29	Johnson et al. (2003b)	1.8	1.8	1.8	0.5	1.0	1.5	0.5	0.8	2.3	1.0	1.3	0.5	0.5	0.0	1.0	1.0	0.0	0.3	1.2	0.5	0.5	Potential
32	Lantican et al. (2005)	3.0	2.5	2.5	2.5	1.0	2.5	2.8	1.3	2.5	1.5	2.3	2.0	1.8	0.0	0.3	0.0	0.0	2.0	2.2	1.4	1.4	Plausible
33	Manyong et al. (2003)	2.3	2.3	2.0	2.0	1.0	1.5	1.8	2.0	2.5	0.0	1.5	1.8	1.8	0.0	1.5	0.0	0.0	1.0	1.7	1.1	1.1	Plausible
36	Morris et al. (2003)	2.5	2.0	2.5	2.0	1.3	2.5	2.5	1.8	3.0	1.0	2.0	2.0	1.8	0.0	0.0	0.0	0.0	1.8	2.0	1.3	1.3	Plausible
42	Rohrbach et al. (1999)	3.0	3.0	2.5	2.0	2.0	2.8	2.5	2.0	2.8	2.0	2.8	1.8	2.5	0.0	0.0	0.0	0.0	2.5	2.4	1.8	1.8	Substantially demonstrated
43	Rueda et al. (1996)	3.0	2.8	2.5	2.0	2.5	3.0	2.3	3.0	1.8	1.3	2.5	1.5	2.5	0.0	2.3	0.0	0.0	1.5	2.4	1.8	1.8	Substantially demonstrated
44	Rutherford et al. (2001)	3.0	3.0	3.0	2.8	3.0	2.5	3.0	3.0	3.0	2.3	3.0	2.8	2.8	0.0	1.5	0.0	0.0	2.5	2.9	2.1	2.1	Substantially demonstrated
49	Tre, J. P. (1995)	3.0	2.0	2.5	2.5	2.5	2.5	2.0	0.0	1.0	0.0	2.0	2.0	1.5	1.0	0.0	2.5	2.5	1.0	1.7	1.4	1.4	Plausible
51	Yapi et al. (1999)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.8	2.8	1.0	2.3	2.5	2.8	2.3	1.8	2.8	2.8	1.8	2.3	2.3	2.3	Substantially demonstrated
52	Zeddies et al. (2001)	2.5	2.5	NA	2.3	NA	2.5	NA	1.8	2.5	1.3	1.3	2.5	1.8	2.5	2.5	0.5	0.5	1.8	2.2	1.8	1.8	Substantially demonstrated

^a Number refers to the study number in Annex A.



CGIAR

**SCIENCE COUNCIL SECRETARIAT
A Unit of the CGIAR System Office**

Viale delle Terme di Caracalla, I-00153 Rome, Italy

www.sciencecouncil.cgiar.org

E-mail: sc-secretariat@fao.org

Tel: +39 06 5705 6696

Fax: +39 06 5705 3298

