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Benefit–cost meta-analysis of investment in the International Agricultural Research Centres

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Benefit–cost meta-analysis of investment in the International Agricultural Research Centres

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Industry and Investment NSW

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Foreword

The Australian Government has supported the International Agricultural Research Centres (IARCs), primarily through the Consultative Group on International Agricultural Research (CGIAR), since their founding in the early 1970s.

Since 1992, this support has largely been channelled through the Australian Centre for International Agricultural Research (ACIAR). For core funding, the priorities are to foster strong linkages between the IARCs, ACIAR and Australian research organisations working together in our partner countries, and to contribute to strengthening of IARC governance to ensure that programs focus on rural poverty and inclusive growth. The priorities for project-specific funding are to strengthen the links between Australian research institutions, the National Agricultural Research Systems (NARS) and the IARCs, and to help focus IARCs on ACIAR's bilateral priorities.

ACIAR focuses its activities within a well-defined set of mandated regions. When this study was commissioned in June 2009, these included North Asia, Papua New Guinea and Pacific island countries, South Asia, South-East Asia and southern Africa. This study examines, in very broad terms, evidence of the returns on investment flowing from research undertaken by the various CGIAR centres across these regions. The main intention was to assess the benefits reported in published economic impact studies in relation to the mandated regions, and to compare these with the total investment in the CGIAR since its establishment.

The study adopted a benefit–cost meta-analysis methodology, which is designed to identify a threshold level of benefits arising from total project expenditure. The benefits are aggregated from individual analyses that meet an established standard for reliability and rigour. From the 27 studies selected for formal assessment, the final analyses involved only those that met the standard of published, reliable and credible economic impacts.

Thus, the assessors have determined that aggregated benefits resulting from this selection process, which represent a lower boundary, constitute a return to ACIAR's mandated regions of at least $2.7 million for every $1 million invested by the CGIAR system. This value most likely will rise significantly once the whole range of possible benefits is considered. Also listed in this report are some of the benefits that have accrued for Australia. All of these add up to a positive outcome, and one that gives impetus for Australia to continue investing, through ACIAR, in the CGIAR system.

Nick Austin
Chief Executive Officer, ACIAR

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIFOR	Center for International Forestry Research
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
IARCs	International Agricultural Research Centres
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRAF	International Centre for Research in Agroforestry, now the World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IITA	International Institute for Tropical Agriculture
ILRI	International Livestock Research Institute
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
NARS	National Agricultural Research System(s)
NPV	net present value
PPI	producer price index

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Summary

The key objective of this study was to provide evidence of how effective Consultative Group on International Agricultural Research (CGIAR) investment in agricultural research and development (R&D) has been in terms of achieving economic impacts within the mandated regions of the Australian Centre for International Agricultural Research (ACIAR). Thus, this study complements the ACIAR bilateral assessments done by Raitzer and Lindner (2005) and builds on the existing meta-analyses undertaken on CGIAR investments by Raitzer (2003) and others, but focuses only on those large-scale, verifiable benefits accruing to areas within ACIAR's mandated regions.

A short list of 27 studies was selected for formal assessment under the credibility assessment framework that rates studies based on elements of 'transparency' and 'demonstration of causality'. Of the 27 studies, 10 were assessed as having 'substantially demonstrated' benefits, 4 were assessed as having 'plausible' benefits, and another 3 were assessed as having 'potential' benefits. Ten studies were excluded after further consideration, for reasons including that their benefits were not reported as net present values (NPVs) or on an appropriate regional scale.

The aggregated benefits from this selection process represent a lower bound of benefits that have been confidently realised as it comprises only those studies for which reliable and credible economic impacts have been published. Although this process will not capture all the economic benefits arising from investment in agricultural research in the mandated regions, it provides a degree of confidence that the benefit:cost ratio reported is reliable.

After implementing this procedure, we estimated that, under the most restricted set of assumptions about credible benefits, every $1 million invested by the CGIAR system in ACIAR's mandated regions produces a return to the developing countries in these regions of at least $2.7 million. Under a more relaxed set of assumptions about credible, plausible and potential benefits the return is up to $3.9 million.

These estimates suggest that continued investment by donor organisations, such as ACIAR, in the CGIAR system will produce high pay-offs, and that by supporting the CGIAR system, some of the benefits achieved are attributable to ACIAR's investment.

Introduction

ACIAR and CGIAR investment in agricultural R&D

The Australian Centre for International Agricultural Research (ACIAR) is an Australian Government statutory authority that operates within the portfolio of the Department of Foreign Affairs and Trade. It was established in 1982 to pursue research into developing more productive and sustainable agricultural systems of benefit to both Australia and developing countries. Given Australia's geographic location and foreign affairs and aid priorities, ACIAR focuses its activities within a well-defined set of mandated regions (primarily North Asia, Papua New Guinea and Pacific island countries, South Asia, South-East Asia and southern Africa).[1] ACIAR's primary interest is in bilateral R&D investments with individual countries within the mandated regions, where ACIAR commissions collaborative research between Australian and developing-country researchers in research areas in which Australia has acknowledged competence. In 2009–10, about two-thirds of ACIAR's research and development budget was allocated to this area of bilateral R&D investment (ACIAR 2010).

ACIAR also administers Australia's contribution to the International Agricultural Research Centres (IARCs) (aciar.gov.au/projects/multilateral/2399). The IARCs that receive ACIAR funding are non-profit institutions, most of which operate as part of the Consultative Group on International Agricultural Research (CGIAR). There are currently 15 IARCs within the CGIAR network, with a combined annual expenditure of almost US$500 million in recent years (cgiar.org/centres). The missions of the international centres focus primarily on delivering agricultural productivity, poverty reduction and environmental sustainability via a diversity of research portfolios covering topics ranging from natural resource management to work on specific crop, livestock and fish commodities (Renkow and Byerlee 2010). Appendix 1 lists the 15 centres and their areas of operation. Renkow and Byerlee (2010) provide a comprehensive review of published CGIAR research impacts and evidence. Their review highlighted areas of CGIAR research yielding the strongest positive impact, namely genetic improvement, pest management and natural resources management and policy.

ACIAR's investment in the CGIAR network supports the core activities of the CGIAR and provides to individual centres specific project funding that is consistent with ACIAR's country program strategies. The goal of ACIAR's multilateral program is to ensure the effectiveness of, and benefits to, developing countries and Australia from agricultural R&D conducted by the IARCs with funds provided by Australia. In 2009/10 this significant investment represented approximately one-third of ACIAR's budget (ACIAR 2010), or about A$18 million. The amount is expected to increase in the near future.

The Impact Assessment Program within ACIAR undertakes and commissions assessments of the pay-off from Australia's investment in international agricultural research. Most of these assessments are of individual bilateral projects, or of broader areas of research or policy interest. The results of these assessments are published on the ACIAR website (aciar.gov.au).

As part of this program of impact assessments, the study reported here was charged with examining in very broad terms the return on investment flowing from

[1] In ACIAR's 2010–11 annual operational plan these have been renamed as, respectively, Papua New Guinea and Pacific island countries; Indonesia, East Timor and the Philippines; Mekong countries and China; South and West Asia; and Sub-Saharan Africa.

research undertaken by the various CGIAR centres across ACIAR's mandated regions. The intention of the study was to assess the benefits reported in published CGIAR economic impact assessments in relation to the mandated regions and to compare these to the total investment in CGIAR undertakings since establishment. The methodology used, benefit–cost meta-analysis, follows that developed by Raitzer (2003).[2] Meta-analysis is used to identify a threshold level of benefits arising from total project expenditure. The benefits are aggregated from individual analyses that meet a set standard for reliability and rigour consistent with that established by Raitzer (2003).

Obtaining a plausible measure of the benefits from CGIAR research activities within ACIAR's mandated regions provides an indication of the effectiveness of the CGIAR in improving the wellbeing of the poor in those regions. By supporting the CGIAR system, it could be said that some of the benefits achieved are attributable to ACIAR's investment. Comparison of CGIAR expenditure in the mandated regions with a measure of reliable benefits for the same areas can be used as an indication of the value of continued investment by ACIAR in the CGIAR system.

This approach has also been used by Raitzer and Lindner (2005) in reviewing the returns from ACIAR's bilateral research and development (R&D) investments, and by Raitzer and colleagues in a suite of subsequent assessments (Raitzer and Kelley 2008a, b; Raitzer et al. 2010) of returns from CGIAR funding.

Background to the methodology

The first impact assessments undertaken by the CGIAR were initiated in 1984 (Raitzer and Kelley 2008a) although it was the late 1990s before an Impact Assessment and Evaluation Group was formed within the CGIAR. This group was later succeeded by the Standing Panel on Impact Assessment (SPIA) (Renkow and Byerlee 2010). More recently, Raitzer (2003) undertook a benefit–cost meta-analysis of investment in the CGIAR system on the basis of published ex-post economic impact assessments from CGIAR centres. A set of principles, criteria and indicators was proposed for appraising the transparency and analytical rigour of the benefits reported in individual economic impact assessments. The intent was to identify a minimum level of aggregated benefits which the CGIAR could be confident had been achieved via its research investment. The benefit thresholds derived were then compared with total CGIAR expenditure over the life of the organisation since 1971.

The benefit–cost meta-analysis approach is conservative in that only those benefits valued in economic terms are included. In addition, not all research investments undertaken by CGIAR centres have been exposed to a complete benefit–cost analysis, as there is no ex-post economic impact information available for many projects. Even by the most conservative criterion, overall benefits attributable to CGIAR research were roughly double the total investment made by the system. In recognition of the undocumented areas of CGIAR research success, Raitzer (2003, p. xvi) stated: 'The true value of benefits arising from the CGIAR is probably in excess of even the upper bounds of the results demonstrated here, as only a small subset of system impacts have been assessed.'

Maredia and Raitzer (2010) recently applied the same procedures to CGIAR and partner investments in agricultural R&D in Sub-Saharan Africa. From an extensive literature review, 23 studies were identified for which aggregate rates of return for R&D investments by the CGIAR and partners had been calculated. These studies were then appraised against the Raitzer (2003) framework of principles, criteria and indicators for study rigour. Subsequently, the economic benefits reported by studies grouped on the basis of their analytical rigour were aggregated and set against total investment by the CGIAR and the National Agricultural Research Systems (NARS) in this region. The study found that aggregate investment was justified under a fairly wide range of assumptions. The total investments by the CGIAR and partners in the region to date were estimated to be some US$16.9 billion (compounded to 2004 US dollars). The documented total benefits aggregated across all the 23, 19 and 9 studies included in the 'potential,' 'plausible' and 'substantially demonstrated' scenarios, respectively, fully recovered

[2] Considerable debate exists about the meaning of the terms meta-analysis and meta-evaluation (see a review in Madzivhandila et al. (2010)). Here the term meta-analysis is used for consistency with earlier studies in this area of work.

this total investment to date when documented benefits included in the analysis were those both 'realised' to date and those projected into the future. Benefit:cost ratios ranged from around 1:1 to 1.64:1.

Raitzer et al. (2010) conducted a review of all documented ex-post impacts of agricultural research in South-East Asia from all sources of research funding, including those outside the CGIAR system. All ex-post impact assessments with South-East Asia coverage were used to provide evidence of the major impacts by type of research and commodity. The authors used this information to explore how the IARCs and the NARS currently allocate research funds in South-East Asia, and to identify gaps in the funding of research areas expected to have high levels of benefits for the poor and the environment (Raitzer et al. 2010). The pool of ex-ante studies used was not filtered using the meta-analysis framework of quality of data and rigour of analysis, but rather represented the complete set of documented ex-post impact assessments for South-East Asia.

Raitzer and Kelley (2008b) investigated how donor agencies use impact assessment evidence, including the type of evidence provided by the meta-analyses described above, to make investment decisions, and whether the assumptions underpinning the accountability of impact assessment were valid. Via a series of surveys and interviews, and by comparing trends in donor funding against impact assessment findings, they found that while impact assessment evidence is not a direct driver of donor decision-making, the confidence that such assessments deliver to donors is of substantial importance for their continued support of the CGIAR system.

Study objective and process

The key objective of the study was to provide an indicator, based on reported economic impact assessments, of how effective investment in CGIAR centres has been in terms of achieving economic impacts within ACIAR's mandated regions. A five-step process was used:

1. The principles, criteria and indicators developed by Raitzer (2003) and others through previous applications of meta-analysis to the ACIAR and CGIAR research systems were reviewed.
2. Published economic impact assessments of CGIAR R&D investments were reviewed and assessed against the criteria identified in step 1.
3. The total annual investment in CGIAR research undertakings from establishment to the present in relation to ACIAR's mandated regions was derived.
4. The benefits from groupings of studies with different levels of rigour are then reported and aggregated for comparison with the total investment from step 3, to derive benefit:cost ratios.
5. Findings in relation to potential threats to validity previously identified in the meta-analysis literature are discussed.

Thus, the present report complements the ACIAR bilateral assessments made by Raitzer and Lindner (2005) and builds on the existing meta-analyses undertaken on CGIAR investments by Raitzer (2003) and others, but focuses only on those large-scale, verifiable benefits accruing to areas within ACIAR's mandated regions. Impact assessments identified in Raitzer (2003) and meta-analyses with coverage of CGIAR system investments subsequently published have been used to avoid duplication of research time and effort. Reflecting this, emphasis was placed on identifying ex-post economic impact assessments for the post-2003 period. Checking for any overlap of reported benefits between the pre-2003 reports and more recent impact assessments was also a priority to avoid potential double-counting of benefits.

Methods

To assess the effectiveness of CGIAR investment in the ACIAR regions of interest, the present study gathered information on the minimum level of benefits achieved through CGIAR research in ACIAR's mandated regions. The information collected related to benefits about which there was a high degree of confidence. The benefits were compared with the total research investment made since 1971 by the CGIAR and its collaborating partners in the mandated regions. Demonstration that a minimum level of reliable benefits exceeds research expenditure is a necessary, if not sufficient, condition for the continued support of the CGIAR system by ACIAR.

Credibility assessment framework

Following on from Raitzer (2003), a benefit–cost meta-analysis approach was applied in this study to examine the question of benefits realised in ACIAR's mandated regions via CGIAR research investments. Benefit–cost meta-analysis is an approach used to assess individual economic impact studies comprising an organisation's research investment portfolio, the organisation in this case being the CGIAR. Individual studies selected for inclusion in the analysis need to meet a set of standards designed to judge the credibility of the estimated research impacts. This step is needed before aggregating the economic benefits for individual projects because the impact assessments for each '… are based on heterogeneous methods and different levels of effort' (Raitzer and Kelley 2008a, p. 109). Two principles were used by Raitzer (2003) to judge the confidence placed on individual impact assessment studies: 'transparency' and 'demonstration of causality'. On the basis of these principles, a set of criteria and indicators was developed to provide a review framework. The criteria and indicators used are shown in Figures 1 and 2. A complete description of the principles, criteria and indicators can be found in Raitzer (2003).

Based on Raitzer (2003), the individual impact assessment studies were scored from 0 to 3 for each indicator shown in Figures 1 and 2, with a score of 3 indicating a high level of satisfaction. From this scoring process, an average score was derived for each of the 'transparency' and 'demonstration of causality' principles. The average score was used to rate the assessments into one of three basic benefit scenarios used to aggregate benefits with differing degrees of reliability (Raitzer 2003; Maredia and Raitzer 2010): 'substantially demonstrated' benefits, 'plausible' benefits and 'potential' benefits. These principles, criteria, indicators and scoring methods were accepted on face value given the need for consistency across studies and the time and resources available.

Scenario 1: Substantially demonstrated benefits. This scenario included only the subset of assessments that achieved an average score of at least 1.5 for both the 'transparency' and 'demonstration of causality' principles. As described in Maredia and Raitzer (2010), this scenario is used to calculate '… a high-confidence 'lower bound' measure of economic impacts…' attributed, in this case, to CGIAR investment within ACIAR's mandated regions.

Scenario 2: Plausible benefits. This scenario included the aggregated benefits from those studies that received a score of at least 1.5 for the indicators under the 'transparency' principle, and an average score of between 1.0 and 1.5 for the indicators under the 'demonstration of causality' principle.

Scenario 3: Potential benefits. This scenario included the aggregated benefits from the remaining studies included in the review that satisfied the overall criteria for inclusion. There is limited certainty that all these benefits have been realised. However, their analysis does provide an indication of the possible level of benefits documented in the literature relevant to CGIAR system investment in the mandated regions.

To avoid duplication of previous research efforts, where ratings were available on assessments included in previous meta-analysis, those ratings were used. The ratings applied are subjective in that they imply judgments against the set of transparency and causality criteria. To minimise the problem of differing rating judgments, several impact assessments reviewed by Raitzer (2003) were independently reviewed and scored

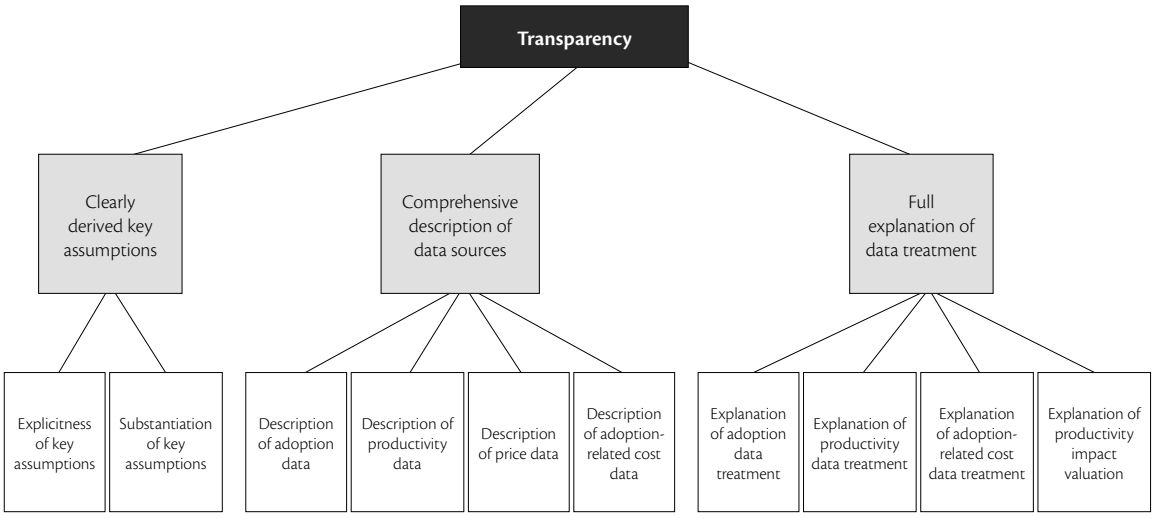

Figure 1. Hierarchical relationship between criteria and indicators for assessing the transparency of the impact assessment studies reviewed. Source: Raitzer (2003, p.11).

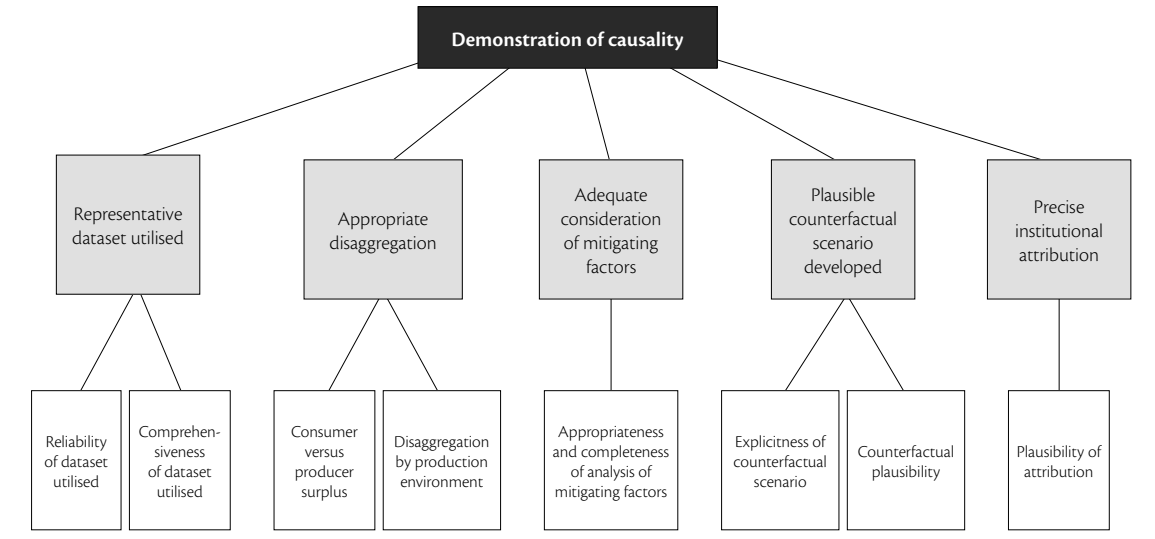

Figure 2. Hierarchical relationship between criteria and indicators for assessing the demonstration of causality within the impact assessment studies reviewed. Source: Raitzer (2003, p.12).

by the authors of this report. The ratings were compared and differences discussed in an effort to ensure that, as far as possible, a consistent rating procedure was applied to the post-2003 studies. The focus of the present study was therefore to extend previous research efforts rather than duplicate them.

Several other studies in this area further split the benefit scenarios into 'realised' and 'realised + projected' subscenarios (Raitzer 2003; Raitzer et al. 2010). That was not done here given the relatively small number of studies that have reported time-series data over the benefit calculation time horizon.

Economic benefits for studies considered in the three scenarios were then aggregated to provide different estimates of benefits arising from the total research portfolio. Next, the aggregated benefits were compared with the total investment made by the CGIAR system, to derive different benefit:cost ratios. For example, the aggregated benefits from this selection process for scenario 1 represent a lower bound of benefits that have been confidently realised as it comprises only those studies for which reliable and credible economic impacts have been published. Although this process will not capture all the economic benefits arising from investment in agricultural research in the mandated areas, it provides a significant degree of confidence that the benefit:cost ratio reported. The degree of confidence in the benefit:cost ratios is less for the groups of studies included in scenarios 2 and 3.

Literature collection, collation and review

Various sources were scanned to develop an initial listing of potential evaluations and assessments. The sources included: impact assessment publications from the CGIAR website (impact.cgiar.org); impact assessments published by individual CGIAR centres (listed in Appendix 1); direct contact with impact assessment staff at CGIAR centres; published book and journal references; and previously published meta-analyses, in particular Raitzer et al. (2010), Raitzer (2003) and Raitzer and Kelley (2008a). All impact assessment or evaluation studies that attributed part of their research activities to CGIAR investment were initially included. Some 400 possibilities were identified. While even this inventory of studies may not be a complete listing of all economic assessments of the impact of agricultural R&D funded by the CGIAR system, it does represent the broadest set achievable within the time frames of this analysis.

Several criteria were used to reduce this list to a more manageable size. First, for the period 1984–2003, only those studies selected by Raitzer (2003) for the CGIAR meta-analysis project were included. All other studies dated earlier than 2003 were excluded. Also excluded were studies that obviously did not cover ACIAR's mandated regions, that did not provide an economic assessment, that provided only an ex-ante assessment, or were earlier versions of published studies or summaries of larger reports. This quickly reduced the list to 66 possibilities, for which reference details are provided separately in Appendix 2.

These possibilities were then considered in more detail. Of the impact assessments selected by Raitzer (2003), 12 were shown to have impacts that fell wholly or partly within ACIAR's mandated regions: 6 studies had direct impacts within the mandated regions and another 6 were reported as having impacts with a 'global' coverage (Table 1). In the studies reporting global impacts, where benefits were specifically identified by region or where sufficient information was provided to enable relevant regional benefits to be calculated, only those benefits relevant to ACIAR's mandated regions were included. Excluded were studies that did not specifically disaggregate the global benefits by region or which provided insufficient information for regional impacts to be calculated. To the extent that benefits from these studies will extend into the mandated areas, the meta-analysis will understate the benefits realised. Although this will reduce the estimated returns from investment in CGIAR centres, the omission of benefits from these studies helps to ensure that the estimate of benefits reported for the mandated areas is a reliable minimal value.

Attention was then given to assessments published since 2003, with Maredia and Raitzer (2010) and Raitzer et al. (2010) being used to help verify the list of post-2003 studies relevant to southern Africa and South-East Asia, respectively. One issue was that, for some of the studies identified and included in the Raitzer (2003) meta-analysis, more recent impact evaluations were available on similar areas of research. An example is

Table 1. Studies from Raitzer (2003) relevant to ACIAR's mandated regions[a]

Study	Time span for benefits	Coverage
Aw-Hassan et al. (2003)	1980–97	Global
Byerlee and Traxler (1995)	1978–90	Global
Heisey et al. (2002)	1997	Global
Johnson et al. (2003a)	1970–98	Global
Johnson et al. (2003b)	1979–98	Global
Morris et al. (2003)	1998	Global
Bantilan and Joshi (1996)	1975–2005	India
Fuglie et al. (1999)	1988–2020	Shandong province, China
Hossain (1998)	1973–93	Bangladesh
Hossain et al. (2003)	1997	Asia
Ryan (1999)	1995–2000	Vietnam
Zeddies et al. (2001)	1974–2013	Africa

[a] Full publication details of the studies cited are given in Appendix 2.

the assessment of the returns from international wheat improvement research. Heisey et al. (2002) and Lantican et al. (2005) are essentially updates of Byerlee and Traxler (1995). In addition, the Marasas et al. (2004) study focused on an area of wheat improvement already included in those broader studies. The Byerlee and Traxler (1995) results could be broken down from global benefits to benefits attributable to ACIAR's mandated regions so, to avoid double counting of benefits, the Heisey et al. (2002) and Lantican et al. (2005) studies could not be included in the final assessment for this report.

Project assessments that were purely ex ante were excluded from the study. This meant that a number of projects with the potential to be already realising significant benefits were not represented in the meta-analysis because they were still awaiting ex-post impact assessment. The research conducted on genetically improved farmed tilapia (Dey 2000) is an example of a project likely to be yielding considerable benefits, but which could not be included in the present study. The net present value (NPV) for this project over the period 1988–2010 was estimated to be US$368 million in 2001 dollars (ADB 2005). Similarly, Raitzer et al. (2010) note that the absence of a traditional ex-post impact assessment since 1999 for the continued uptake of modern rice varieties in South-East Asia means that the true extent of the benefits realised from genetic research to improve rice productivity remains unknown and likely understated.

Studies that reported only per hectare or per household impacts were not included in the analysis as there were no data provided in these studies on which to scale-up the per unit information to determine reliable region-level impacts.

In some impact assessments, the NPV of the research was not reported. However, where estimates of the cash flow of benefits, costs or net benefits were provided, these were converted to present value (PV) estimates using a discount rate of 5%. This is consistent with Raitzer et al. (2010, p. 88) who identify 5% as the discount rate commonly applied to ex-post impact assessments.

Finally, several published ACIAR studies that were jointly funded under ACIAR's bilateral and multilateral funding arrangements were excluded to avoid any possible double counting with the Raitzer and Lindner (2005) assessment of bilateral ACIAR investment. Therefore, the basis for the screening of impact assessments undertaken for this study can be summarised as follows:

i. an economic focus

ii. published post-2003 impact assessments—to avoid duplicating previous studies

iii. impact assessments relevant to ACIAR's mandated regions only

iv. ex-post impact assessments

v. assessments reporting NPVs or time series of benefits and costs.

Appendix 2 lists all 66 studies initially considered in detail. The first part of the list gives the 27 that were selected to warrant formal examination under the credibility assessment framework. The remaining 39 were excluded on the basis of one or more of the abovementioned criteria.

Deflating and discounting

The base currency for all costs and benefits included in the present analysis is 2008 US dollars, with the final results also reported in Australian dollar equivalents.

Initially, the strategy was to attempt to collect and collate a set of nominal US$ benefit streams for each study. The nominal benefits reported for each study would then be aggregated to produce total annual benefit streams for each benefit scenario (i.e. plausible etc.), then converted to 2008 US$ using the US producer price index (PPI) (Raitzer 2003) to determine real values. The real annual stream of total benefits in 2008 US$ would then be discounted using a 5% real discount rate. Sensitivity testing would be undertaken using 0% and 10% rates, as these span the recommended discount rate of 5% for ACIAR's individual impact assessments (Raitzer and Lindner 2005). According to Raitzer et al. (2010, p. 18), this range also reflects '… a realistic range of potential returns to long-term private-sector alternative investments'.

Where individual studies provided benefit streams in real US$ values only, nominal values could be obtained by rebasing the PPI series to the appropriate year.

The benefit–cost analysis of aggregate costs and benefits can be expressed algebraically as follows (Raitzer et al. 2010):

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

$$TC_u = \sum_{t=f}^{j} \frac{G_t + N_t}{(1+r)^{t-T}} \quad (2)$$

$$BCR_u = \frac{TV_u}{TC_u} \quad (3)$$

$$NPV_T = \sum_{t=f}^{n} \frac{B_t - (G_t + N_t)}{(1+R)^{t-T}} = 0 \quad (4)$$

where

TV	=	total value of benefits assessed
u	=	scenario under which estimate is generated
t	=	year
T	=	2008 (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 2008 US$)
B_t	=	benefit value across all the studies in time period t
r	=	discount rate
R	=	internal rate of return (i.e. the discount rate for which NPV = 0)
TC	=	total costs of CGIAR and partner investment
f	=	first year of the cost series (1972)
j	=	most recent year of CGIAR investment (2007)
G	=	expenditures by the CGIAR system
N	=	costs by research partner
BCR	=	benefit:cost ratio
NPV	=	net present value.

On completion of these calculations, the summary statistics were converted into A$ values using the average US$/A$ exchange rate for 2008 (A$1.00 = US$0.8632).

Limitations of the analysis

Several limitations of the analysis have already been mentioned. The present study includes the benefits from any impact studies that attributed part of their research activities to the CGIAR. As such, it is the aggregate benefit of research undertaken by the CGIAR and its collaborators that is reflected in the numerator. Attribution of a portion of benefits to the CGIAR alone, based on investment made in proportion with collaborators, has not been undertaken (although in some other studies this has been done by using crude approximations, such as 50:50).

The reasons for exclusion of studies that reported only per hectare or per household impacts have already been given. Where only global-level benefits were reported, efforts were made to extract only regional benefits related to ACIAR's mandated regions. For example, information contained in Byerlee and Traxler (1995, p. 276) was used to apportion the global benefits calculated in that study to just the ACIAR mandated region of interest. Again, information in the study relating to shares of output was used to apportion the whole-of-Africa benefits reported in Zeddies et al. (2001) to just southern Africa.

In some studies it was not possible to extract regional information on benefits associated with the geographic focus of this study. A possible option would have been to apportion the benefits on a share-of-production basis but, for many of the commodities involved, production shares have been quite volatile and, given the focus on the time patterns of costs and benefits, it was decided not to introduce this potential source of error. To that extent, some of the benefits from CGIAR system research that have made a significant contribution within ACIAR's mandated areas are not included in this analysis. An example of a major set of such benefits on this criterion is covered by Gollin (2006).

A further limitation relates to the extent to which the preferred benefit-calculation strategy could be followed. Unfortunately, time-series data on either nominal or real benefit streams were available for only five studies. Authors of a number of other studies were contacted in an attempt to obtain further details on the stream of benefits to enable their inclusion in this study. Unfortunately, the information required was not forthcoming. David Raitzer was also contacted to source the stream of benefits collected directly from authors of studies included in his 2003 report, but that information was no longer available.

Limitations affecting the methodology of the present study and of ex-post benefit–cost analysis more broadly are the absence of non-monetary impacts and unquantified negative impacts. Kelley et al. (2008, p. 210) raise the need for ex-post impact assessments to identify '… indicators of impact not amenable to monetary valuation such as biodiversity, social gains, environmental protection and strengthened institutions'. Within the scope of this study it has not been possible to account for the adverse or negative economic impacts of CGIAR research over time. In their benefit–cost meta-analysis of investment in CGIAR IARCs, Raitzer and Kelley (2008a, p.114) describe the assumption that CGIAR research has not resulted in any 'poisoned wells' as 'speculative'. The same limitation applies to the present study. Raitzer and Kelley (2008a) further note that there has been

> … no systematic quantitative effort to-date … to analyse the impacts of unintended or inappropriate outputs within the CGIAR (such as accidental pest introductions), and it is likely that if such mistakes were indeed made, they would be very difficult to accurately attribute to specific actions or actors.

Of the net benefits reported here, the distribution of benefits and costs within the economy will vary. There will be some groups that benefit, but others may incur an economic loss, and the distribution of such impacts is unknown.

Results

CGIAR investment in ACIAR's mandated regions, 1972–2008

To complete the cost side of the analysis, an estimate is required of the cost of the CGIAR system in ACIAR's mandated regions for 1972–2008.

At the time of finalising this report, time-series data on the cost of the CGIAR system were available by individual centre but, unfortunately, not by geographic location. These data are shown in Appendix 3. Excluding the African Rice Centre whose R&D activities lie completely outside of the mandated regions for ACIAR investment, the total investment by the remaining 14 CGIAR centres totalled US$7.5 billion in nominal terms over the period 1972–2007.

The use of total CGIAR investment expenditure as the denominator in the meta-analysis will be an overestimate of the actual CGIAR system expenditure in the mandated regions relevant to the present study. For example, Raitzer et al. (2010) estimated the proportion of the budgets of IARCs attributable to South-East Asia in 2008 to be US$63.1 million or 12% of total IARC expenditure across the 14 centres (Table 2). To have information like this across all ACIAR's mandated regions would be ideal.

A possible option would be to calculate cost shares based on production of the major commodities by centre, but again these shares have been quite volatile in the past and significant errors could be introduced.

Credibility assessment framework

From the revised list of possible inclusions (Appendix 2), 27 studies were selected for formal assessment under the credibility framework. After closer examination, however, 10 of them were excluded. The main reason was either that only global benefits were stated and it was not possible, with any credibility, to disaggregate by mandated region, or that the benefits were very small. Thus, 17 studies were subsequently subjected to the study's rigorous scoring procedure. Some of these studies had already been scored during previous analyses (Raitzer 2003; Maredia and Raitzer 2010; Raitzer et al. 2010). Where this was the case, the earlier scores were applied directly. Where there were no previous scores, the studies were scored independently by the authors then crosschecked for consistency. An option would have been to re-score all studies and compare the assessments across the different groups of evaluators, but since the focus was on consistency with previous work that course was not followed.

Of the 17 studies, 10 were assessed as having 'substantially demonstrated' benefits: that is, each of them received average scores of 1.5 or greater for both the 'transparency' and 'demonstration of causality' principles. These 10 studies are listed in Appendix 4, together with some details of their benefit values.

Another four studies were assessed as having 'plausible' benefits: that is, each of them received an average score of at least 1.5 for the indicators under the 'transparency' principle, and an average score of 1.0 or greater for the indicators under the 'demonstration of causality' principle. These four studies are listed in Appendix 5.

Table 2. Estimated International Agricultural Research Centre expenditure in South-East Asia, 2008

International Agricultural Research Centre	Total (US$ million)	South-East Asia (US$ million)	Share (%)
WorldFish Center	20.8	9.9	48
Center for International Forestry Research	20.6	6.9	34
International Rice Research Institute	41.4	13.7	33
World Agroforestry Centre	28.3	7.5	27
International Food Policy Research Institute	48.3	6.4	13
International Water Management Institute	25.2	3.2	13
Bioversity International	37.9	3.8	10
International Potato Center	27.6	2.3	8
International Livestock Research Institute	42.6	3.1	7
International Center for Tropical Agriculture	47.3	2.0	4
International Maize and Wheat Improvement Center	41.7	1.8	4
International Institute for Tropical Agriculture	51.0	–	0
International Crops Research Institute for the Semi-Arid Tropics	47.9	–	0
International Center for Agricultural Research in the Dry Areas	32.0	–	0
TOTAL	512.6	60.6	12

Source: Raitzer et al. (2010, p. 17)

The final three studies were assessed as having 'potential' benefits: that is, they each received an average score of less than 1.5 for the indicators under the 'transparency' principle, and/or an average score of less than 1.0 for the indicators under the 'demonstration of causality' principle. These three studies are listed in Appendix 6.

Some broad characteristics of the 17 studies assessed are given in Table 3.

Aggregated credible benefits, 1972–2018

The economic benefits from each of the three sets of studies as defined in Appendixes 4, 5 and 6 were collated. This was done using two different methods.

Substantially demonstrated benefits—time-series data

As noted above, time-series data on either nominal or real benefit streams were available for only five studies: Fan et al. (2006), Hossain (1998), Raitzer (2008), Templeton and Jamora (2008) and Zeddies et al. (2001). Fortunately, the benefits from each of these studies were assessed as substantially demonstrated.

The aggregated benefit data from these five studies are presented in Table 4, along with the cost data described above, in both nominal and real terms. At this stage, no discounting is applied. Based only on the five studies that have been assessed as substantially demonstrated, we can say that we have a high degree of confidence that CGIAR investment within ACIAR's mandated regions has produced benefits in the order of US$20 billion in the dollar values of the years in which the benefits were accrued, or in the order of US$30 billion if the benefit stream is expressed in 2008 US dollars.

Total expenditure by the CGIAR system (excluding only the African Rice Centre) totalled some US$7.5 billion in the dollar values of the years in which these costs were incurred, or in the order of US$11 billion if the cost stream is expressed in 2008 US dollars.

Table 3. Broad characteristics of the studies assessed

Study	CGIAR centre[a]	Commodity	Country/region	Benefit (net present value, 2008 US$ million)
Substantially demonstrated				
Bantilan and Joshi (1996)	ICRISAT	Pigeon pea	India	327
Byerlee and Traxler (1995)	CIMMYT	Wheat	Share to South Asia	9,429
Fan et al. (2006)	IRRI	Rice	India and China	23,186
Fuglie et al. (1999)	CIP	Sweetpotato	Shandong province, China	372
Hossain (1998)	IRRI	Rice	Bangladesh	8,603
Raitzer (2008)	CIFOR	Pulp and paper	Indonesia	26
Rohrbach et al. (1999)	ICRISAT	Pearl millet	Namibia	276
Ryan (1999)	IFPRI	Rice	Vietnam	62
Templeton and Jamora (2008)	IRRI	Rice	Philippines	278
Zeddies et al. (2001)	IITA	Cassava	Share for southern Africa	836
Plausible				
Aw-Hassan et al. (2003)	ICRISAT	Lentil	Bangladesh	246
Hossain et al. (2003)	IRRI	Rice	South-East Asia	5,772
Johnson et al. (2003)	CIAT	Cassava	Southern Africa	137
Morris et al (2003)	CIMMYT	Maize	Asia and southern Africa	197
Potential				
Ajayi and Place (2006)	ICRAF	Tree forage	Zambia	24
Dey et al. (2007)	WorldFish	Aquaculture	Malawi	4
Shrestha et al. (2006)	IRRI	Rice	Laos	72

[a] ICRISAT = International Crops Research Institute for the Semi-Arid Tropics; CIMMYT = International Maize and Wheat Improvement Center; IRRI = International Rice Research Institute; CIP = International Potato Center; CIFOR = Center for International Forestry Research; IFPRI = International Food Policy Research Institute; IITA = International Institute for Tropical Agriculture; CIAT = International Center for Tropical Agriculture; ICRAF = World Agroforestry Center

Comparing the total benefits from the five studies and the total costs of the CGIAR (excluding the African Rice Centre) indicates a surplus of benefits over costs of some US$12.5 billion in nominal values or some US$19 billion in 2008 US dollars. This produces a benefit:cost ratio of around 2.7:1. Based only on the data for the five studies provided in Table 4, every million US dollars invested by the CGIAR system in ACIAR's mandated regions produces a return of around US$2.7 million to the developing countries in these regions.

As noted above, this level of return should be considered to be very much a lower-bound, conservative estimate. For a start, almost the whole costs of the CGIAR system have been included, rather than just those expended in ACIAR's mandated regions. At this stage we do not have a good grasp of what might be the split between mandated and non-mandated regions, but it could well be that the costs used to date are overestimates by a factor of two or more. Second, the benefit stream is based on just the five studies about which we are most confident. There are at least another 12 studies from the

Table 4. Aggregated real costs and benefits, five 'substantially demonstrated' studies only[a], 1972–2018 (US$ million)

Year	Nominal benefits	Nominal costs	Nominal net cash flow	US PPI[b]	Real benefits[c]	Real costs[c]
1972	–	13.1	−13.100	0.236	0.000	55.605
1973	41.788	19.5	22.288	0.257	162.493	75.825
1974	51.176	24.6	26.576	0.297	172.562	82.949
1975	64.039	35.4	28.639	0.329	194.920	107.750
1976	52.765	47.7	5.065	0.343	153.848	139.079
1977	60.390	66.0	−5.610	0.365	165.337	180.695
1978	80.316	80.8	−0.484	0.394	203.929	205.159
1979	91.441	91.6	−0.159	0.438	208.954	209.318
1980	126.594	104.8	21.794	0.497	254.962	211.069
1981	155.949	113.4	42.549	0.542	287.487	209.050
1982	324.674	122.8	201.874	0.564	575.484	217.663
1983	401.253	140.4	260.853	0.573	699.906	244.900
1984	460.392	149.1	311.292	0.585	786.613	254.748
1985	466.964	144.7	322.264	0.590	790.980	245.104
1986	471.806	164.1	307.706	0.583	809.953	281.712
1987	513.086	172.3	340.786	0.594	863.125	289.847
1988	572.595	225.3	347.295	0.609	939.745	369.763
1989	638.654	244.2	394.454	0.641	997.003	381.221
1990	744.215	247.1	497.115	0.672	1,107.264	367.642
1991	2,456.010	247.3	2,208.710	0.687	3,576.811	360.155
1992	2,609.795	266.3	2,343.495	0.695	3,754.758	383.130
1993	1,955.204	264.5	1,690.704	0.704	2,778.407	375.863
1994	1,472.114	283.6	1,188.514	0.708	2,078.727	400.463
1995	1,003.864	285.0	718.864	0.722	1,390.840	394.864
1996	954.901	290.6	664.301	0.741	1,289.326	392.374
1997	1,042.962	293.5	749.462	0.744	1,402.530	394.686
1998	1,149.477	298.1	851.377	0.737	1,559.371	404.400
1999	866.917	286.5	580.417	0.751	1,155.056	381.725
2000	789.916	297.6	492.316	0.779	1,014.339	382.151
2001	28.962	290.3	−261.338	0.794	36.484	365.690
2002	29.947	329.7	−299.753	0.784	38.220	420.780
2003	28.609	345.1	−316.491	0.808	35.387	426.860
2004	29.039	361.9	−332.861	0.838	34.657	431.916

Table 4. (continued)

Year	Nominal benefits	Nominal costs	Nominal net cash flow	US PPI[b]	Real benefits[c]	Real costs[c]
2005	29.300	386.4	−357.100	0.879	33.341	439.692
2006	30.562	389.4	−358.838	0.905	33.785	430.463
2007	30.807	434.0	−403.193	0.940	32.770	461.651
2008	29.488	–	29.488	1.000	29.488	–
2009	29.770	–	29.770	1.025	29.044	–
2010	27.744	–	27.744	1.051	26.408	–
2011	27.993	–	27.993	1.077	25.994	–
2012	27.250	–	27.250	1.104	24.687	–
2013	24.076	–	24.076	1.131	21.280	–
2014	15.284	–	15.284	1.160	13.180	–
2015	14.547	–	14.547	1.189	12.237	–
2016	13.843	–	13.843	1.218	11.362	–
2017	13.173	–	13.173	1.249	10.548	–
2018	11.290	–	11.290	1.280	8.819	–
2019	–	–	–	1.312	–	–
2020	–	–	–	1.345	–	–
Total	20,061	7,557	12,504		29,832	10,976

[a] Hossain (1998); Zeddies et al. (2001); Fan et al. (2006); Raitzer (2008); Templeton and Jamora (2008)

[b] Producer price index, 2008 base year

[c] 2008 US dollars

CGIAR centres that have been assessed as producing benefits to ACIAR's mandated regions.

The temporal pattern of benefits and costs is also of interest. In real terms, aggregate costs grew steadily to around US$300 million in 1987, and since then have fluctuated in a fairly narrow band between US$360 and US$460 million per annum. Aggregate benefits, on the other hand, greatly exceeded costs during the 1980s and 1990s, but have fallen away rapidly during the last decade. This is of course a function of the particular studies included and their individual time frames.

Because the time pattern of costs and benefits is so different, different discount rates may have an influence on the summary statistics of aggregate benefits and costs. Some sensitivity analyses of different discount rates are reported in Table 5.

As shown in Table 5, the different discount rates scale the present values but do not alter the benefit:cost ratio to any significant degree. Thus, based on just the five studies about which we are most confident, we calculate that the CGIAR investment within ACIAR's mandated regions has produced net benefits in the order of US$31.9 billion in real 2008 US dollars when discounted at 5%. Every million US$ dollars invested by the CGIAR system in ACIAR's mandated regions produces a return of at least US$2.8 million to the developing countries in these regions.

Substantially demonstrated benefits—aggregate data

Another way to look at the benefits from CGIAR investments in ACIAR's mandated regions is to examine the data reported in Appendixes 4, 5 and 6.

Table 5. Sensitivity of real 'substantially demonstrated' benefits and real costs to different discount rates (2008 US$ million)

Discount rate (%)	Present value of benefits	Present value of costs	Net present value	Benefit:cost ratio
0	29,832	10,976	18,912	2.72:1
5	49,268	17,397	31,870	2.83:1
10	23,845	8,951	14,894	2.66:1

In Table 3 and Appendix 4 the five studies included in Tables 4 and 5 above report an aggregate NPV of benefits of $32.9 billion in real 2008 US dollars, very close to the figure of US$31.9 billion calculated by a different method and given in Tables 4 and 5. Table 3 and Appendix 4 include another five studies assessed as substantially demonstrated, in addition to those included in Table 4 (although only three of the studies described in this table contribute more than 90% of the impact). Here, just NPVs are reported, so we have to assume that each study has used approximately the same discount rate (taken as 5%). After we re-base the reported benefits to 2008 values and make any adjustments needed to account for benefits accruing outside the mandated regions, we calculate aggregate discounted real net benefits of some US$43.4 billion. Most of this benefit additional to that already counted in Table 4 is due to the results of the Byerlee and Traxler (1995) study of the benefits of international wheat breeding research. With total costs of US$17.4 billion at a 5% discount rate, these additional net benefit values push the aggregate discounted real gross benefits up to US$60.8 billion or the benefit:cost ratio to 3.5:1. Under these assumptions, every million US dollars invested by the CGIAR system in ACIAR's mandated regions produces a return of around US$3.5 million to the developing countries in these regions.

Plausible benefits—aggregate data

In Table 3 and Appendix 5 there are four studies assessed as plausible, although just one of them (Hossain et al. 2003) contributes more than 90% of the impact. Again, just NPVs are reported here, so we have to assume that each study has used approximately the same discount rate (5%). After we re-base the reported benefit values to 2008 values and make any adjustments necessary to account for benefits accruing outside of the mandated regions, we calculate aggregate real net benefits of some US$6.4 billion.

These plausible benefit values added to those calculated under the substantially demonstrated scenario increase the aggregate real gross benefit to US$67.2 billion which, when compared to the aggregate real costs of US$17.4 billion, results in a benefit:cost ratio of 3.9:1. Under these more relaxed assumptions about the credibility of the benefit estimates, every million US dollars invested by the CGIAR system in ACIAR's mandated regions produces a return of around US$4 million to the developing countries in these regions.

Potential benefits—aggregate data

Finally, in Table 3 and Appendix 6 there are three studies assessed as potential. The benefit values attributed to these studies are quite small in relation to the values in Appendixes 4 and 5. After going through the same procedure as for Appendix 5, we calculate aggregate real benefits of only US$100 million, which does not change either the aggregate benefits or the benefit:cost ratio to any appreciable extent.

Discussion and conclusion

Based on only the five studies that have been assessed as substantially demonstrated, and where annual benefit streams were available, we can say that we have a high degree of confidence that the CGIAR investment within ACIAR's mandated regions has produced undiscounted benefits in the order of US$30 billion over the period 1972–2018 when the benefit stream is expressed in 2008 US dollars ($35 billion in 2008 Australian dollars).

Undiscounted total expenditure by the CGIAR system (excluding only the African Rice Centre) over the period 1972–2007 aggregates to some US$11 billion when the cost stream is expressed in 2008 US dollars (A$13 billion).

Comparing the total undiscounted benefits and total undiscounted costs indicates a surplus of benefits over costs of some US$19 billion in 2008 US dollars (A$22 billion). This produces a benefit:cost ratio of around 2.7:1. Every million dollars invested by the CGIAR system in ACIAR's mandated regions produces a return of around $2.7 million to the developing countries in these regions. When the benefit and cost streams are discounted at a rate of 5%, the benefits and costs are much larger in terms of 2008 values since the great majority of the benefits and costs have occurred in the past and are therefore compounded forward to 2008 values. Nevertheless, the benefit:cost ratio for the discounted benefits and costs remains about the same at 2.8:1.

As noted earlier, this level of return should be considered to be very much a lower-bound, conservative estimate. For a start, almost the whole costs of the CGIAR system have been included, rather than just those costs expended in ACIAR's mandated regions. At this stage we do not have a good grasp of the split between mandated and non-mandated regions, but it could well be that the costs used to date are overestimates by a factor of two or more. Second, the benefit stream is based on just the five studies in which we have most confidence. There are at least another 12 studies that have been assessed as producing benefits to ACIAR's mandated regions. When these additional benefits are added, and both costs and benefits are discounted at 5%, the aggregate discounted real benefit increases to over US$67 billion (A$78 billion), which results in a benefit:cost ratio of 3.9:1. Under these more relaxed assumptions about the credibility of the benefit estimates, every million dollars invested by the CGIAR system in ACIAR's mandated regions produces a return of around $4 million to the developing countries in these regions.

In summary, we have estimated that every $1 million invested by the CGIAR system in ACIAR's mandated regions produces a return to the developing countries in these regions of at least $2.7 million under the most restricted set of assumptions about credible benefits, and up to $4 million under a more relaxed set of assumptions about credible, plausible and potential benefits.

Given the very conservative approach adopted in this report, in terms of which studies to include and in valuing only those benefits that are credible, the estimate of a benefit:cost ratio ranging between 2.7:1 and 3.9:1 sits comfortably with the statement in a recent release from the CGIAR that: 'For every $1 invested in CGIAR research, $9 worth of additional food is produced in developing countries, where it is needed most' (cgiar.org/who/index.html). Comparing our results with those of other studies, we note that Raitzer (2003) found a benefit:cost ratio of around 2:1 for expected benefits from the whole CGIAR system, Maredia and Raitzer (2010) found benefit:cost ratios for Sub-Saharan Africa to be less than 2:1 and Hazell (2009) found a benefit:cost ratio of around 15:1 for CGIAR investments in South Asia.

There are several data problems constraining a more comprehensive assessment.

First, we have not been able to disaggregate expenditure by the individual CGIAR centres into investments inside or outside ACIAR's mandated regions.

Second, at the time of writing, time-series data on either nominal or real benefit streams were available for only five studies. Fortunately, each of these studies was assessed as substantially demonstrated, so proper discounting of the various benefit and cost streams could be undertaken with the most rigorous set of benefit estimates. The same degree of rigour could not be applied to the plausible and potential benefit studies.

Third, there are 10 studies that were initially considered to be potential inclusions but which have currently been excluded for various reasons. Some of them could be included if we had more information on the regional distribution of the benefits. Further examination is therefore warranted for this group of studies, with special attention to a detailed investigation of production shares of the major commodities supplied from inside ACIAR's mandated regions.

Fourth, the analysis has been constrained to benefits accruing in the specified ACIAR mandated regions. However, ACIAR is expected to generate benefits to Australian primary production sectors as well as those in the mandated regions. Some prominent examples of studies that have examined these R&D spill-in issues from the CGIAR system are those conducted by John Brennan and colleagues in the grains area. Brennan and Bantilan (1999), for example, calculated the spillovers into the Australian grain sorghum and chickpea industries from the results of ICRISAT research. They found that ICRISAT varieties would likely result in a cost reduction for sorghum of A$4.02 per tonne and, for chickpeas, A$39.18 per tonne in Western Australia and A$8.78 per tonne in the rest of Australia. This was calculated to result in an aggregate discounted benefit of some A$36 million over the period 1999–2022, or about A$1.5 million per annum. Similarly, Brennan et al. (2002) found that the spillovers from ICARDA results into the Australian cereal grain and pulse industries would likely result in a total discounted benefit to Australia of some A$13.7 million per annum over the period 2001–22. Finally, Brennan and Quade (2004) found that the Australian wheat industry has been affected in two ways by CIMMYT's wheat-breeding program. First, Australia's wheat yields increased by an average of 4.6% up to 2001. On the downside, however, CIMMYT's global success has resulted in 7.4% lower world prices for wheat, including that from Australia. The estimated net effect over the period 1965 to 2020 is a net loss of welfare of A$673 million, which is equivalent to a loss to the Australian wheat industry of A$12 million per annum.[3]

Thus, the developing countries in ACIAR's mandated regions benefit from ACIAR's investment in the CGIAR system, and Australia is affected as well, from spillover benefits (and costs) into Australian primary production industries.

Notwithstanding the evidence of strong positive impact shown in this and other studies, Renkow and Byerlee (2010, p. 24) identify a need for evaluation work to demonstrate stronger 'links between CGIAR investments and development goals of reducing poverty and hunger, promoting gender equality, and enhancing environmental sustainability'. What need to be developed are impact assessment systems that encourage evaluators to report time series of benefit and cost calculations as well as the broad summary measures. How to disaggregate costs and benefits across the range of social and market groups that are the stakeholders should also be investigated.

In summary, these estimates suggest that continued investment in the CGIAR system will produce high pay-offs. Moreover, given ACIAR invests in the CGIAR system, through both project-specific and unrestricted funds, then it could be argued that a proportion, even if not readily quantifiable, of the benefits is attributable to ACIAR's investment.

[3] However, if Australia did not invest in CIMMYT via its overall investment in the CGIAR system, and therefore did not have ready access to the new varieties, the loss would have been even greater. So the investment in CIMMYT actually resulted in a net benefit.

Appendix 1 Active CGIAR centres[4]

Centre	Headquarters	Mandated regions
International Center for Tropical Agriculture (CIAT)	Cali, Columbia	Latin America and Caribbean, Africa and Asia
Center for International Forestry Research (CIFOR)	Bogor, Indonesia	Latin America, Africa and Asia
International Maize and Wheat Improvement Center (CIMMYT)	El Batan, Mexico	Global
International Potato Center (CIP)	Lima, Peru	South and South-East Asia and the Pacific, Latin America and the Caribbean, Southwest and Central Asia, Sub-Saharan Africa
International Center for Agricultural Research in the Dry Areas (ICARDA)	Allepo, Syria	North Africa, Nile Valley and Sub-Saharan Africa, West Asia, Arabian Peninsula, The Highlands, Latin America
WorldFish Center (formerly International Center for Living Aquatic Resources Management, ICLARM)	Penang, Malaysia	Asia, Africa, South Pacific
World Agroforestry Centre (formerly International Center for Research in Agroforestry, ICRAF)	Nairobi, Kenya	South-East Asia, Eastern Africa, Latin America, Southern Africa, West and Central Africa, South Asia
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Hyderabad, India	West and Central Africa, Eastern and Southern Africa, Asia
International Food Policy Research Institute (IFPRI)	Washington, DC, United States	Sub-Saharan Africa, North Africa, Middle East and Western Asia, South Asia and Central Asia, East Asia and South-East Asia, Latin America and the Caribbean
International Water Management Institute (IWMI)	Battaramulla, Sri Lanka	East, Southern and West Africa, Central, South and South-East Asia
International Institute for Tropical Agriculture (IITA)	Ibadan, Nigeria	Sub-Saharan Africa
International Livestock Research Institute (ILRI)	Nairobi, Kenya	Sub-Saharan Africa, South Asia
Bioversity International	Rome, Italy	Global
International Rice Research Institute (IRRI)	Los Baños, Philippines	Global, in particular Asia and Africa
Africa Rice Centre (West African Rice Development Association) (WARDA)	Bouake, Côte d'Ivoire, and Cotonou, Benin	West, Central, East and North African regions

4 In 1994, the International Livestock Centre for Africa (ILCA) and the International Laboratory for Research on Animal Diseases (ILRAD) merged to form ILRI. In 1994, the International Network for the Improvement of Banana and Plantain (INIBAP) became a program of Bioversity International. In 2004, the International Service for National Agricultural Research was dissolved and the main programs moved to IFPRI.

Appendix 2 List of case studies considered for inclusion

Studies warranting formal assessment

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Appendix 3 Total expenditure by the CGIAR network, 1972–2007

Appendix 3 Total expenditure by the CGIAR network, 1972–2007 (US$ million)

Year	CIAT	IFPRI	CIMMYT	ILRI	ICRISAT	IRRI	Bioversity International	World Agroforestry	ICARDA	CIP	IWMI	WorldFish Center	CIFOR	ISNAR	Total
1972	4.3		5.0		0.3	3.0				0.5					13.1
1973	6.1		6.3		2.7	3.1				1.3					19.5
1974	5.5		6.1	1.0	3.8	6.0				2.2					24.6
1975	6.0	0.3	7.6	3.7	6.1	8.5	0.5			2.7					35.4
1976	6.3	0.8	8.7	8.9	6.8	9.7	0.9		1.5	4.1					47.7
1977	9.5	1.2	10.1	11.9	9.8	12.0	1.3		4.6	5.6					66.0
1978	11.7	1.6	12.7	15.2	12.6	12.4	1.7		7.5	5.4					80.8
1979	13.4	1.9	14.9	16.2	11.8	13.8	2.4		10.1	7.1					91.6
1980	15.0	2.5	16.6	18.9	12.3	15.9	3.0		11.8	7.7				1.1	104.8
1981	16.2	2.8	18.4	18.5	13.0	17.2	3.0		13.1	9.0				2.2	113.4
1982	18.6	3.1	18.3	16.9	15.9	19.5	3.6		15.0	9.6				2.3	122.8
1983	21.7	3.8	17.5	19.8	21.0	20.2	3.6		19.7	10.1				3.0	140.4
1984	23.5	4.3	20.7	21.9	21.0	19.7	4.0		21.0	9.7				3.3	149.1
1985	21.2	4.4	19.4	22.5	20.3	21.0	4.2		17.8	10.2				3.7	144.7
1986	22.0	4.9	21.3	25.8	25.0	24.2	5.1		18.0	13.3				4.5	164.1
1987	24.1	6.0	23.3	25.7	26.2	24.9	5.5		18.3	12.8				5.5	172.3
1988	28.3	9.1	31.3	31.2	36.4	33.7	6.2		20.1	20.1				8.9	225.3
1989	32.6	10.9	34.1	34.5	36.3	33.9	7.6		22.6	21.9				9.8	244.2
1990	32.4	12.3	32.5	34.8	38.1	39.4	7.6		18.7	21.3				10.0	247.1
1991	33.0	13.4	34.1	33.4	35.3	38.1	8.7		19.5	21.5				10.3	247.3
1992	23.4	13.0	31.4	28.5	34.7	41.5	12.4	12.5	18.4	20.9	9.0	6.8	3.2	10.6	266.3

Appendix 3 (continued)

Year	CIAT	IFPRI	CIMMYT	ILRI	ICRISAT	IRRI	Bioversity International	World Agroforestry	ICARDA	CIP	IWMI	WorldFish Center	CIFOR	ISNAR	Total
1993	30.1	12.9	29.3	22.2	31.5	43.6	13.2	13.4	16.3	20.6	9.2	6.8	5.1	10.3	264.5
1994	33.6	13.8	31.2	29.1	30.8	39.8	14.5	17.0	19.0	22.8	8.9	6.6	6.1	10.4	283.6
1995	31.5	13.8	31.7	29.6	30.0	38.1	12.6	16.9	19.3	23.2	10.2	7.8	9.0	11.3	285.0
1996	31.0	16.0	28.9	28.3	29.7	38.3	16.4	17.4	21.1	24.2	10.0	9.6	9.0	10.7	290.6
1997	31.7	18.2	28.6	26.1	27.7	35.4	18.8	21.8	22.3	23.4	10.0	9.0	10.6	9.9	293.5
1998	32.1	20.1	30.1	24.6	26.5	34.8	21.2	20.4	25.2	22.2	9.4	10.6	11.3	9.6	298.1
1999	28.7	20.8	33.8	26.6	21.2	32.5	20.1	20.6	19.5	20.0	8.8	14.2	11.5	8.2	286.5
2000	29.7	21.5	37.9	23.1	21.9	33.8	22.8	21.5	22.6	20.5	8.8	12.3	12.4	8.8	297.6
2001	27.5	21.7	39.3	24.3	20.4	30.3	22.3	21.6	21.1	18.7	10.8	12.1	12.3	7.9	290.3
2002	32.6	23.5	41.5	28.8	24.8	33.6	25.7	21.9	24.3	19.3	20.8	12.3	11.7	8.9	329.7
2003	32.9	26.5	37.5	31.0	24.0	28.8	28.3	27.4	26.2	17.6	23.0	15.5	13.6	12.8	345.1
2004	36.7	31.4	41.1	31.7	26.8	32.9	32.0	28.5	24.6	21.5	23.1	14.1	15.1	2.4	361.9
2005	42.4	39.7	38.8	32.2	28.4	33.4	34.6	30.0	29.1	22.0	23.1	15.2	17.5		386.4
2006	41.8	39.1	37.4	34.8	34.0	33.3	34.6	31.9	27.0	22.9	20.6	15.5	16.5		389.4
2007	48.9	45.7	43.9	40.6	37.8	37.7	37.6	30.4	27.1	26.1	24.0	17.3	16.9		434.0

Appendix 3 (continued)

CIAT = International Center for Tropical Agriculture; IFPRI = International Food Policy Research Institute; CIMMYT = International Maize and Wheat Improvement Center; ILRI = International Livestock Research Institute; ICRISAT = International Crops Research Institute for the Semi-Arid Tropics; IRRI = International Rice Research Institute; ICARDA = International Center for Agricultural Research in the Dry Areas; CIP = International Potato Center; IWMI = International Water Management Institute; CIFOR = Center for International Forestry Research; ISNAR = International Service for National Agricultural Research

Data sources:

1972–97	Tables I–2, CGIAR contributions to the agreed research agenda by centre, 1972–1997 (millions). Figures shown for 1972–1980 are total expenditures (operations/capital) and may be higher or lower than the contributions for that year (because of the accounting convention followed in the 1970s). worldbank.org/html/cgiar/publications/finance/cg97fin.pdf
1998–2000	Table A1.2, CGIAR contributions to the research agenda by centre, 1972–2001 worldbank.org/html/cgiar/publications/annreps/cgar01/cgfinrep2001.pdf
2001–05	2005 financial report, Table A3.1, CGIAR expenditure by centre, 2001–2005 cgiar.org/pdf/cgiar_finreport_2005.pdf
2006–07	2007 financial report,Table 3, financial results by centre (expenditure) cgiar.org/publications/annual/pub_ar2007/pdf/08CGIARFullFinRprt_june13.pdf

Excludes African Rice Centre as completely outside ACIAR's mandated regions

Appendix 4 Benefits from studies assessed as substantially demonstrated

Study[a]	Time period of benefits[b]	Base year and units	Total benefits[c,d]	US producer price index inflating factor[e]	Total[f]	Adjustment for mandated regions[g]	Total[f]
Bantilan and Joshi (1996)	1975–2005	US$ 1990 m	220	0.672	327	1.0	327
Byerlee and Traxler (1995)	1978–1990	US$ 1990 m	9,750	0.672	14,509	0.65	9,430
Fan et al. (2006)	1981–2000	US$ 2000 m	18,056	0.779	23,178	1.0	23,178
Fuglie et al. (1999)	1988–2020	US$ 1990 m	250	0.672	372	1.0	372
Hossain (1998)	1973–1993	US$ 1990 m	5,782	0.672	8,604	1.0	8,604
Raitzer (2008)	1998–2017	US$ 2006 m	23	0.905	25	1.0	25
Rohrbach et al. (1999)	1991–1995	US$ 2004 m	231	0.838	276	1.0	276
Ryan (1999)	1995–2000	US$ 1995 m	45	0.722	62	1.0	62
Templeton and Jamoram (2008)	1989–2018	US$ 2007 m	261	0.940	278	1.0	278
Zeddies et al. (2001)	1974–2013	US$ 1994 m	9,372	0.708	13,237	0.0632	837

a Full reference details are provided in Appendix 2.

b As reported in study

c To end of study period

d In dollar values for year of calculation

e 2008 base

f 2008 dollar values

g Authors' adjustments based where possible on data contained in the original studies

Appendix 5 Benefits from studies assessed as plausible

Study[a]	Time period of benefits[b]	Base year and units	Total benefits[c,d]	US producer price index inflating factor[e]	Total[f]	Adjustment for mandated regions[g]	Total after adjustment[f]
Aw-Hassan et al. (2003)	1980–1997	US$1990m	330	0.672	491	0.5	246
Hossain et al. (2003)	1997	US$1990m	4,310	0.672	6,413	0.9	5,772
Johnson et al. (2003)	1998	US$1990m	100.78	0.737	137	1.0	137
Morris et al. (2003)	1998	US$1990m	440	0.672	655	0.3	197

a Full reference details are provided in Appendix 2.

b As reported in study

c To end of study period

d In dollar values for year of calculation

e 2008 base

f 2008 dollar values

g Authors' adjustments based where possible on data contained in the original studies

Appendix 6 Benefits from studies assessed as potential

Study[a]	Time period of benefits[b]	Base year and units	Total benefits[c,d]	US producer price index inflating factor[e]	Total[f]	Adjustment for mandated regions[g]	Total after adjustment[f]
Ajayi et al. (2006)	2004	US$1990m	21	0.905	24	1.0	24
Dey et al. (2007)	1994–2016	US$1990m	3	0.794	4	1.0	4
Shrestha et al. (2006)	1990–2020	US$1990m	60	0.838	72	1.0	72

a Full reference details are provided in Appendix 2.

b As reported in study

c To end of study period

d In dollar values for year of calculation

e 2008 base

f 2008 dollar values

g Authors' adjustments based where possible on data contained in the original studies

Appendix 7 Sample of studies excluded

Study[a]	Time period of benefits[b]	Base year and units	Benefits[c]	Reason for exclusion
Aw-Hassan et al. (2009)	1999–2013			Only average annual benefit figures are provided. Time series or stream of net benefits reported not available.
Dalton et al. (2005)	1994–2003	2003 US$	$2.5m	Benefits very small
Erenstein et al. (2007)	2003–04	2003 US$	$23.9m per annum	Extrapolates benefits for case study region to one-third of wheat–rice area of India and Pakistan, but also provides evidence of substantial disadoption of the technology, which suggests scaling up is not realistic.
Gollin (2006)	1960–2000	2000 US$	$143m per annum for wheat, $149m per annum for maize	Global benefits only—paper does not separate benefits by region
Heisey et al. (2002)	1997	1995 US$	$880m	Global benefits reported. Unable to identify benefits within mandated regions.
Hu et al. (2007)		2006 US$	$0.67 billion per annum	Ex-ante analysis. Village level per hectare fertiliser savings are extrapolated to national figure to suggest potential whole-of-country savings.
Lantican et al. (2005)	2002	2002 US$	$0.5–3.9 billion per annum depending on yield and attribution assumptions	Benefits reported at only a global scale
La Rovere et al. (2009)	2002–06			Ex-ante analysis and benefits not within ACIAR mandated regions

Appendix 7 (continued)

Study[a]	Time period of benefits[b]	Base year and units	Benefits[c]	Reason for exclusion
Laxmi et al. (2007)				Ex-ante impact assessment
Marasas et al. (2004)	1973–2007	2004 US$	$5.36 billion	Global benefits reported, but broken down into 'mega-environments' based on CIMMYT classification. Potential overlap of benefits with spring wheat in Byerlee and Traxler (1995) study. No time series of benefits are available.

a Full reference details are provided in Appendix 2.

b As reported in study

c Where reported

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No.	Author(s) and year of publication	Title	ACIAR project numbers
1	Centre for International Economics 1998.	Control of Newcastle disease in village chickens	AS1/1983/034, AS1/1987/017 and AS1/1993/222
2	George P.S. 1998.	Increased efficiency of straw utilisation by cattle and buffalo	AS1/1982/003, AS2/1986/001 and AS2/1988/017
3	Centre for International Economics 1998.	Establishment of a protected area in Vanuatu	ANRE/1990/020
4	Watson A.S. 1998.	Raw wool production and marketing in China	ADP/1988/011
5	Collins D.J. and Collins B.A. 1998.	Fruit fly in Malaysia and Thailand 1985–1993	CS2/1983/043 and CS2/1989/019
6	Ryan J.G. 1998.	Pigeonpea improvement	CS1/1982/001 and CS1/1985/067
7	Centre for International Economics 1998.	Reducing fish losses due to epizootic ulcerative syndrome—an ex ante evaluation	FIS/1991/030
8	McKenney D.W. 1998.	Australian tree species selection in China	FST/1984/057 and FST/1988/048
9	ACIL Consulting 1998.	Sulfur test KCL–40 and growth of the Australian canola industry	PN/1983/028 and PN/1988/004
10	AACM International 1998.	Conservation tillage and controlled traffic	LWR2/1992/009
11	Chudleigh P. 1998.	Postharvest R&D concerning tropical fruits	PHT/1983/056 and PHT/1988/044
12	Waterhouse D., Dillon B. and Vincent D. 1999.	Biological control of the banana skipper in Papua New Guinea	CS2/1988/002-C
13	Chudleigh P. 1999.	Breeding and quality analysis of rapeseed	CS1/1984/069 and CS1/1988/039
14	McLeod R., Isvilanonda S. and Wattanutchariya S. 1999.	Improved drying of high moisture grains	PHT/1983/008, PHT/1986/008 and PHT/1990/008
15	Chudleigh P. 1999.	Use and management of grain protectants in China and Australia	PHT/1990/035
16	McLeod R. 2001.	Control of footrot in small ruminants of Nepal	AS2/1991/017 and AS2/1996/021
17	Tisdell C. and Wilson C. 2001.	Breeding and feeding pigs in Australia and Vietnam	AS2/1994/023
18	Vincent D. and Quirke D. 2002.	Controlling *Phalaris minor* in the Indian rice–wheat belt	CS1/1996/013
19	Pearce D. 2002.	Measuring the poverty impact of ACIAR projects—a broad framework	
20	Warner R. and Bauer M. 2002.	*Mama Lus Frut* scheme: an assessment of poverty reduction	ASEM/1999/084
21	McLeod R. 2003.	Improved methods in diagnosis, epidemiology, and information management of foot-and-mouth disease in Southeast Asia	AS1/1983/067, AS1/1988/035, AS1/1992/004 and AS1/1994/038
22	Bauer M., Pearce D. and Vincent D. 2003.	Saving a staple crop: impact of biological control of the banana skipper on poverty reduction in Papua New Guinea	CS2/1988/002-C
23	McLeod R. 2003.	Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia and the epidemiology and control of bovine ephemeral fever in China	AS1/1984/055, AS2/1990/011 and AS2/1993/001
24	Palis F.G., Sumalde Z.M. and Hossain M. 2004.	Assessment of the rodent control projects in Vietnam funded by ACIAR and AUSAID: adoption and impact	AS1/1998/036

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No.	Author(s) and year of publication	Title	ACIAR project numbers
25	Brennan J.P. and Quade K.J. 2004.	Genetics of and breeding for rust resistance in wheat in India and Pakistan	CS1/1983/037 and CS1/1988/014
26	Mullen J.D. 2004.	Impact assessment of ACIAR-funded projects on grain-market reform in China	ANRE1/1992/028 and ADP/1997/021
27	van Bueren M. 2004.	Acacia hybrids in Vietnam	FST/1986/030
28	Harris D. 2004.	Water and nitrogen management in wheat–maize production on the North China Plain	LWR1/1996/164
29	Lindner R. 2004.	Impact assessment of research on the biology and management of coconut crabs on Vanuatu	FIS/1983/081
30	van Bueren M. 2004.	Eucalypt tree improvement in China	FST/1990/044, FST/1994/025, FST/1984/057, FST/1988/048, FST/1987/036, FST/1996/125 and FST/1997/077
31	Pearce D. 2005.	Review of ACIAR's research on agricultural policy	
32	Tingsong Jiang and Pearce D. 2005.	Shelf-life extension of leafy vegetables—evaluating the impacts	PHT/1994/016
33	Vere D. 2005.	Research into conservation tillage for dryland cropping in Australia and China	LWR2/1992/009 and LWR2/1996/143
34	Pearce D. 2005.	Identifying the sex pheromone of the sugarcane borer moth	CS2/1991/680
35	Raitzer D.A. and Lindner R. 2005.	Review of the returns to ACIAR's bilateral R&D investments	
36	Lindner R. 2005.	Impacts of mud crab hatchery technology in Vietnam	FIS/1992/017 and FIS/1999/076
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38	ACIAR 2006.	Future directions for ACIAR's animal health research	
39	Pearce D., Monck M., Chadwick K. and Corbishley J. 2006.	Benefits to Australia from ACIAR-funded research	FST/1993/016, PHT/1990/051, CS1/1990/012, CS1/1994/968, AS2/1990/028, AS2/1994/017, AS2/1994/018 and AS2/1999/060
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42	Pearce D. and Monck M. 2006.	Benefits to Australia of selected CABI products	
43	Harris D.N. 2006.	Water management in public irrigation schemes in Vietnam	LWR2/1994/004 and LWR1/1998/034
44	Gordon J. and Chadwick K. 2007.	Impact assessment of capacity building and training: assessment framework and two case studies	CS1/1982/001, CS1/1985/067, LWR2/1994/004 and LWR2/1998/034
45	Turnbull J.W. 2007.	Development of sustainable forestry plantations in China: a review	
46	Monck M. and Pearce D. 2007.	Mite pests of honey bees in the Asia–Pacific region	AS2/1990/028, AS2/1994/017, AS2/1994/018 and AS2/1999/060

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No.	Author(s) and year of publication	Title	ACIAR project numbers
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48	Longmore C., Gordon J. and Bantilan M.C. 2007.	Assessment of capacity building: overcoming production constraints to sorghum in rainfed environments in India and Australia	CS1/1994/968
49	Fisher H. and Gordon J. 2007.	Minimising impacts of fungal disease of eucalypts in South-East Asia	FST/1994/041
50	Monck M. and Pearce D. 2007.	Improved trade in mangoes from the Philippines, Thailand and Australia	PHT/1990/051 and CS1/1990/012
51	Corbishley J. and Pearce D. 2007.	Growing trees on salt-affected land	FST/1993/016
52	Fisher H. and Gordon J. 2008.	Breeding and feeding pigs in Vietnam: assessment of capacity building and an update on impacts	AS2/1994/023
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54	Monck M. and Pearce D. 2008.	Impact of improved management of white grubs in peanut-cropping systems	CS2/1994/050
55	Martin G. 2008.	ACIAR fisheries projects in Indonesia: review and impact assessment	FIS/1997/022, FIS/1997/125, FIS/2000/061, FIS/2001/079, FIS/2002/074, FIS/2002/076, FIS/2005/169 and FIS/2006/144
56	Lindner B. and McLeod P. 2008.	A review and impact assessment of ACIAR's fruit-fly research partnerships—1984 to 2007	CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1994/115, CS2/1996/225, CS2/1997/101, CS2/1998/005, CS2/2003/036, CP/2007/002, CP/2007/187, PHT/1990/051, PHT/1994/133, PHT/1993/87, CP/1997/079, CP/2001/027 and CP/2002/086
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63	Harding M., Tingsong Jiang and Pearce D. 2009.	Analysis of ACIAR's returns on investment: appropriateness, efficiency and effectiveness	
64	Mullen J.D. 2010.	Reform of domestic grain markets in China: a reassessment of the contribution of ACIAR-funded economic policy research	ANRE1/1992/028 and ADP/1997/021

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No.	Author(s) and year of publication	Title	ACIAR project numbers
65	Martin G. 2010.	ACIAR investment in research on forages in Indonesia	AS2/2000/124, AS2/2001/125, AS2/2000/103, LPS/2004/005, SMAR/2006/061 and SMAR/2006/096
66	Harris D.N. 2010.	Extending low-cost fish farming in Thailand: an ACIAR–World Vision collaborative program	PLIA/2000/165
67	Fisher H. 2010.	The biology, socioeconomics and management of the barramundi fishery in Papua New Guinea's Western Province	FIS/1998/024
68	McClintock A. and Griffith G. 2010	Benefit–cost meta-analysis of investment in the International Agricultural Research Centres	

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