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Review

The impacts of CGIAR research: A review of recent evidence

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ABSTRACT

We review evidence on the impacts of CGIAR research published since 2000 in order to provide insight into how successfully the CGIAR Centers have been in pursuing the System's core missions. Our review suggests that CGIAR research contributions in crop genetic improvement, pest management, natural resources management, and policy research have, in the aggregate, yielded strongly positive impacts relative to investment, and appear likely to continue doing so. Crop genetic improvement research stands out as having had the most profound documented positive impacts. Substantial evidence exists that other research areas within the CGIAR have had large beneficial impacts although often locally and nationally rather than internationally. However, the "right-time, right-place" nature of successful policy research and the relatively limited geographic scale of much natural resource management research often limits the overall scale of impacts of these programmatic thrusts vis-à-vis genetic improvement research. We conclude that given the evidence available, the CGIAR's portfolio of research allocations has become overly skewed toward natural resource management and policy research over time. Hence, restoring somewhat the share of resources allocated to crop genetic improvement is warranted. In addition, the CGIAR needs to prioritize impact assessment of resource management and policy research to deepen its understanding of the social and environmental impacts of its work.

Introduction

The Consultative Group on International Agricultural Research (CGIAR) is nearly four decades old. Founded in 1971, the CGIAR currently comprises a group of 15 international agricultural research centers whose core missions include agricultural productivity growth, poverty reduction, and environmental sustainability. Since its inception, the CGIAR has been associated with some phenomenal successes in pursuing these missions – most notably, the large increases in the productivity of Asian rice and wheat farmers in the Green Revolution. A large literature documents substantial pro-poor impacts of international agricultural R&D generally, and research conducted under the aegis of the CGIAR specifically (e.g., Thirtle et al., 2003; Adato and Meinzen-Dick, 2007).

The 15 member Centers of the CGIAR focus on a range of activities and operate semi-autonomously in pursuing their specific research agenda (Table 1). Some have worldwide mandates for promoting the productivity of specific crops, livestock, and fish commodities. Others focus on multiple commodities within production systems in specific agro-ecologies. Still others concentrate on research related to natural resource management or to policies.

Not surprisingly for a System encompassing such a highly diverse portfolio of research activities, some Centers have been more successful in generating positive measurable impacts than others. Even certain programs within otherwise very successful Centers, have at times suffered rather poor records in terms of returns on research investments. Some of this is likely attributable to normal cycles in scientific discovery. But there is growing concern that slow growth in core funding since the early 1990s, in conjunction with an expanding portfolio of research initiatives, has eroded the System's effectiveness in fulfilling its various objectives (CGIAR, 2008). Indeed, the CGIAR itself has recognized these weaknesses and embarked on a far reaching reform process scheduled for implementation in 2010.

Reflecting these concerns, formal impact assessment has become increasingly institutionalized within the CGIAR over the past ten years as demands have escalated for quantifiable assessments of the impacts of Centers' specific research activities. Simply put, donors and CGIAR administrators have placed increased pressure on CGIAR research managers to demonstrate that research investments represent money well spent.

The emphasis on impact assessment was institutionalized within the CGIAR with the formation of the Impact Assessment and Evaluation Group in the late 1990s and has been intensified

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Table 1
International agricultural research centers of the CGIAR.

Center	Location	Year of entry into CGIAR	Mandate and/or commodity	Regional focus
Africa Rice Center (formerly WARDA)	Benin	1975	Rice	Sub-Saharan Africa
Bioversity International (formerly IPGRI)	Italy	1974	Plant genetic resources	Global
CIAT – International Center for Tropical Agriculture	Colombia	1971	*Phaseolus* beans, cassava	Global
CIFOR – Center for International Forestry Research	Indonesia	1993	Sustainable forestry mgmt	Global
CIMMYT – International Maize and Wheat Improvement Center	Mexico	1971	Maize, wheat	Global
CIP – International Potato Center	Peru	1973	Potatoes, sweet potatoes, other root crops	Global
ICARDA – International Center for Agricultural Research in the Dry Areas	Syria	1975	Barley, lentils, fava beans, wheat, chickpeas	Middle East, North Africa
ICRISAT – International Crops Research Institute for the semi-arid tropics	India	1972	Sorghum, millets, pigeonpeas, chick-peas, groundnuts	Semi-arid tropics (Asia and Africa primarily)
IFPRI – International Food Policy Research Institute	USA	1980	Policy	Global
IITA – International Institute of Tropical Agriculture	Nigeria	1971	Cassava, maize, cowpeas, yams soybeans, bananas, plantains	Africa
ILRI – International Livestock Research Institute	Kenya	1995[a]	Livestock	Global (emphasis on Africa)
IRRI - International Rice Research Institute	Philippines	1971	Rice	Global
IWMI – International Water Management Institute	Sri Lanka	1991	Irrigation, water mgmt.	Global
ICRAF – World Agroforestry Centre	Kenya	1991	Agroforestry, multi-purpose trees	Global
WorldFish Center (formerly ICLARM)	Malaysia	1992	Aquatic resources management	Global

[a] Merger of two livestock Centers that were previously members of the CGIAR.

through the activities of its successor, the Standing Panel on Impact Assessment (SPIA), which is now part of the CGIAR's Science Council. SPIA has vigorously promoted the development of methods for doing *ex post* impact assessment (Walker et al., 2008a). Historically, much of this effort has been directed at impacts of crop genetic improvement research (Kelley et al., 2008). More recently, SPIA has promoted application of these methods to other types of CGIAR research, including natural resource management and policy analysis (Waibel and Zilberman, 2007; CGIAR Science Council, 2008).

There is thus a large and growing body of work assessing impacts of a wide variety of CGIAR research using state-of-the-art evaluation techniques. However, for research that focuses on knowledge-based innovations in policy design and natural resource management, the state-of-the-art is in many instances not as well developed as might be desired. This is due to extremely formidable challenges in isolating lines of causality, attributing impacts to various participants in the research process, developing meaningful counterfactuals, and even in establishing meaningful quantitative measures of impact (Kelley et al., 2008).

This review summarizes published evidence on the impacts of CGIAR research from 2000. Its goal is to provide insight into how successfully the CGIAR Centers have been in pursuing the core missions of the System. In particular, we orient our review around the relative performance of different programmatic thrusts – genetic improvement, pest management, natural resource management, and policy-oriented research. For the most part, the focus is on assessments of impacts on human well being appearing in peer reviewed publications after 2000, although some 'gray literature' when deemed credible is cited to include very recent studies. Inevitably, because of long lags between completion of a research project and its impacts, many of the *ex post* analyses surveyed here reflect impacts of research carried out prior to 2000. In addition, the impacts of many of the core activities of the System such as knowledge production and dissemination through publication, germplasm collections, and capacity building have not yet been rigorously evaluated and are not included this review. Finally, the CGIAR Centers conduct practically all of their research with partners, especially national research systems. Some studies have partitioned benefits based on rules of thumb such as the origin of parent materials in improved varieties. However, for much research, the research products are co-produced, and benefits reported reflect the contribution of CGIAR partners as well.

Genetic improvement research

Crop genetic improvement (CGI) has historically been the bread and butter of the CGIAR. Improved germplasm for use by national programs, either for direct release or as parent material, is a classic international public good that from the early years of the CGIAR has demonstrated large spillovers across regions and countries (Maredia and Byerlee, 2000). Despite this, CGI has received a sharply declining share of the CGIAR core funding over time, falling from 25% to 16% between 1992 and 2005 (Pingali and Kelley, 2007).[2]

Since the 1980s the impacts of CGI have been fairly consistently tracked at the global level for some crops especially rice, wheat, maize, and potatoes. These studies, along with a major System-wide analysis of impacts of CGI completed in 2003 (Evenson and Gollin, 2003), have consistently found high rates of return to the CGIAR investment in these crops. This is not surprising given the broad geographic scale, reaching tens of millions of hectares, over which the diffusion of improved varieties occurs. That the benefits have been so well-chronicled reflects the relatively straightforward nature of quantifying benefits associated with productivity increases and attributing those benefits to specific CGIAR research investments. In addition, methods for evaluating the impacts of CGI are well established in the literature, notwithstanding some questions of partitioning benefits between the CGIAR and national systems.[3,4]

Comprehensive global assessments of CGI

The first (and only) comprehensive global evaluation of the impacts of the CGIAR in CGI was undertaken by Evenson and Gollin

[2] For example, funding for CGI declined by more than 50% for wheat in CIMMYT and maize in IITA from their peaks in the 1980s (Byerlee and Dubin, 2008; Alene et al., 2009).

[3] In addition, most studies tend not to explicitly address counterfactual scenarios of technology products that would have been produced (by alternative sources) in a world without the CGIAR – Evenson and Rosegrant (2003) being a notable exception.

[4] Although the CGIAR also works on livestock, fisheries and forestry, it only has a comparable program in genetic improvement of fish for aquaculture (and to a much smaller degree livestock). Some case-study based impact assessment studies exist for genetically improved tilapia (e.g., ADB, 2005; Deb and Dey, 2006). However, the projected impacts are mainly of an *ex ante* nature and are therefore not included in this review.

Table 2
CGIAR contribution to adoption of modern varieties and yield growth in developing countries, 1965–1998.

Crop	Area (million ha) in developing countries, 1998	Estimated number of variety releases, 1965–1998	Share area to modern varieties, 1998	Share modern variety area to CGIAR cross, 1998	Share modern variety area to any CGIAR ancestry, 1998	CGI contribution (all sources) to yield growth, 1965–1998 (%/year)	CGIAR's CGI contribution to yield growth, 1965–1998 (%/ year)
Wheat	120	2188	0.82	0.32	0.64	0.96	0.52–0.62
Rice	150	1484	0.64	0.29	0.58	0.79	0.33–0.37
Maize	97	1494	0.87	0.23	0.55	0.67	0.19–0.20
Sorghum	39	363	0.44	0.22	0.38	0.50	0.19–0.20
Millet	36	123	0.44	0.27	0.85	0.57	0.51–0.55
Barley	20	105	0.49	0.50	0.80	0.49	0.24–0.28
Lentils	3	49	0.23	0.70	0.90	0.28	0.11–0.14
Beans	23	642	0.18	0.75	0.90	0.21	0.09–0.13
Cassava	17	252	0.15	0.74	0.93	0.22	0.03–0.05
Potatoes	9	458	0.88	0.08	0.17	0.74	0.09–0.10
All	**535**	**7246**	**0.65**	**0.30**	**0.60**	**0.72**	**0.25–0.28**

Source: Evenson (2003a,b). Area and area shares under MVs computed from Evenson (2003a) to 1998 FAOSTAT area data.

Table 3
CGIAR contribution to adoption of modern varieties and yield growth (all crops) by region, 1965–1998.

Region	Area (million ha) in developing countries, 1998	Estimated number of variety releases, 1965–1998	Share area to modern varieties, 1998	Share modern variety area to CGIAR cross, 1998	Share modern variety area to any CGIAR ancestry, 1998	Total genetic improvement contribution to yield growth, 1965–1998 (%/ year)	CGIAR genetic improvement contribution to yield growth, 1965–1998 (%/ year)
Latin America	57	3146	0.51	0.28	0.55	0.66	0.35–0.39
Asia	337	2229	0.83	0.26	0.57	0.88	0.35–0.39
MENA	49	715	0.56	0.50	0.81	0.69	0.33–.39
SS Africa	92	1157	0.23	0.38	0.62	0.28	0.11–13
All	**535**	**7246**	**0.65**	**0.30**	**0.60**	**0.72**	**0.25–.33**

Source: Same as Table 2.

(2003). This study covered research carried out on 10 crops at eight Centers over the period 1965–1998 (Evenson, 2003a,b). It analyzed the use of CGIAR germplasm in released varieties and subsequent yield impacts and global economic benefits generated by these varieties.

The impact of CGI generally, and the central role of the CGIAR specifically, is clear for almost all crops (Table 2). As expected, impacts have been greatest in rice, wheat, and maize in terms of both area influenced and adoption. For these three crops, CGI has had the largest impacts on yield growth, contributing from 0.7–1.0% annually. Note, however, that impacts for so-called 'orphan' crops – i.e., crops other than rice, wheat and maize – accelerated toward the end of the period studied. The use of CGIAR germplasm products has been even higher in released varieties of so-called orphan crops produced almost exclusively in the tropics and subtropics, although areas under cultivation remain comparatively lower globally. Overall, 65% of the area of the 10 food crops listed in Table 2 is planted with improved varieties. Sixty percent of this area is sown to varieties with CGIAR ancestry, and half of these are derived from crosses made at a CGIAR Center (i.e., direct releases by national systems).

Among regions, impacts have been highest in Asia (both in relative and absolute terms) and lowest in Africa (Table 3). In India, Fan et al. (2007) attributes between 12% and 64% of the estimated $3.6 billion gain from rice improvement research up to 2000 to IRRI. By contrast, only 11% of Africa's crop area is estimated to be sown to improved varieties linked to CGIAR research, with correspondingly much lower benefits (Maredia and Raitzer, 2006). This partly reflects the distribution of crops between the regions – orphan crops are more important in Africa. But even for the same crop, impacts have generally been lower in Africa. This may well be a reflection of the late start to CGIAR breeding work in that region. For example, it was only in the mid-1980s that CIMMYT established its first serious maize breeding program for Africa. However, infrastructural and institutional constraints likely played a critical role as well.

Estimates of the overall benefits of CGIAR's contribution to CGI are extraordinarily large – in the billions of dollars. Most of these benefits are produced by the three main cereals. Raitzer and Kelley (2008) summarizes average annual benefits for CGIAR research for spring bread wheat, rice (Asia only), and maize (CIMMYT only) of $2.5, $10.8 and $0.6–0.8 billion, respectively. Evenson and Gollin (2003) estimated rates of return to the CGIAR's investment in CGI research ranging from 39% in Latin America to over 100% in Asia and MENA.[5]

An important question for this review is whether or not these large benefits from CGI have been maintained in the past decade. Answering this question is constrained by the paucity of global evidence since the Evenson–Gollin study was completed. At a global and regional level, CIMMYT continued conducting impact studies up to 2005 for wheat (with data ending in 2002). These indicated similar if not higher benefits (Table 4). CIP too has recently published a global review of impacts of potato crop improvement research that shows that varieties carrying CIP parentage are now

[5] Evenson and Rosegrant (2003) used a global model of food supply and demand to quantify the counterfactual of what would have happened to the world food economy absent CGIAR contributions. They found that: (a) world food production would have been 4–5% lower; (b) world grain prices would have been 18–21% higher; (c) area planted to food crops would have been expanded by 11–13 million hectares in developing countries, sometimes at the expense of primary forests and fragile lands with high biodiversity; (d) per capita food consumption in developing countries would have been 5% lower on average, and up to 7% lower in the poorest regions; and (e) some 13–15 million additional children would have been malnourished, predominantly in South Asia.

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Table 4
Estimates of economic benefits to international wheat-breeding research.

Study	Period covered	Benefits from all breeding	Benefits attributed to CIMMYT-national network
Byerlee and Traxler (1995)	1966–1990	$3.0 billion per year internal rate of return of 53%	$1.5 billion per year
Heisey et al. (2003) mid-range estimate	1996–1997	$2.4 billion per year	$1.1 billion per year
Lantican et al. (2005): mid-range estimate	1988–2002	$3.4–4.8 billion per year	$1.0–1.8 billion per year
Marasas et al. (2004): leaf rust resistance only	1973–2007		$5.4 billion net present value

sown on over 1 million ha (Thiele, 2008, p. 12). Their adoption has more than doubled since the earlier published figures shown in Table 2.

Emerging success stories in Africa

A number of very recent studies point to emerging successes in sub-Saharan Africa. These assessments inevitably are at least partially *ex ante* in nature, given that the full benefits of widespread adoption are yet to unfold.

The Evenson and Gollin (2003) study highlighted significant adoption of improved maize varieties and hybrids in sub-Saharan Africa. A recent study by Alene et al. (2009) documents continued success on this front. Their analysis of maize improvement research in West and Central Africa from 1971 to 2005 indicates that some 60% of the maize area in the region is now covered by improved varieties, the great majority with parentage from the CGIAR (IITA and CIMMYT). Benefits from CGIAR investments in maize are estimated to exceed $2.9 billion with an increasing trend over time, and an overall rate of return to research investment (CGIAR and national) of 43%.

Collaborative research between IITA and ILRI has led to the development of genetically improved dual-purpose cowpea varieties with substantial promise for dry savannah regions of West Africa. Ex ante estimates of the present value of net benefits from the IITA/ILRI research and extension efforts over the period 2000–2020 range from $299 million to $1.1 billion (Kristjanson et al., 2002). Depending on different assumptions, internal rates of return (IRRs) between 50% and 103% were found, and estimated benefit-cost ratios range from 32 to 127.

A recently completed study by Kalyebara et al. (2008) estimates that new varieties of the common bean (*Phaseolus vulgaris*) developed by CIAT through participatory breeding methods have been adopted on about half of the total bean area in East, Central and Southern Africa, reaching some 5.3 million households over a period of 17 years. They project a net present value of benefits of nearly $200 million (against total investment costs of $16 million), and an IRR of 81% the period 1986–2015.

Participatory variety selection has also been used for over ten years for selection of so-called new rice for Africa (NERICA) upland rice varieties in Africa, especially with participation of women farmers. NERICAs were developed to combine the high productivity traits of Asian rice and the tolerance of African rice varieties to drought, weeds and pests.[6] Studies at the country level suggest substantial local impact on farm incomes and food security from NERICA adoption (Diagne, 2006; Kijima et al., 2006). Still, adoption has been much slower than originally anticipated.

Impacts on poverty

The bulk of the impact work has focused on estimating aggregate returns and the efficiency of the research investment. Yet investors in the CGIAR wish to see more evidence of impacts on developmental goals such as reducing poverty and hunger, and sustainable management of natural resources and the environment. Some such studies are now emerging. Fan et al. (2007), for example, provide macro-level evidence for China and India linking IRRI rice research on MV rice to poverty reduction. They found that between 1981 and 1999 more than 6.75 million Chinese were moved out of poverty due to IRRI's research. In India the numbers are even more impressive: 14 million people rising above the poverty line between 1991 and 1999.

The Fan et al. study found that lower food prices resulting from increased aggregate production were the main pathway by which MV rice reduced poverty in China and India.[7] However, the bulk of these impressive poverty reduction accomplishments occurred in the early part of the time period analyzed, with the marginal contribution to poverty reduction declining rather precipitously over time. In contrast, Alene et al. (2009) estimate that maize research in West and Central Africa has moved 740,000 people out of poverty annually, with the rate of exit increasing over time. These differences probably relate to the fact that many African farmers are still adopting the first generation of improved varieties.

Yield stability

Yield stability is important for all farmers, but especially for poor farmers whose food security and livelihood are vulnerable to pest and disease outbreaks, droughts, and other stresses. While early studies suggested that yields of improved varieties may be more variable than those they replaced (Anderson and Hazell, 1989), recent evidence suggests that later generations of improved varieties have stabilized yields. For example, Gollin (2006) concluded that the variability of maize and wheat yields measured by the coefficient of variation around trends over the past 40 years has declined in developing countries. This decline is statistically associated with the spread of improved varieties, even after controlling for increased use of irrigation and other inputs. The annual value of benefits from improved yield stability in maize and wheat alone are estimated at $149 and $143 million, respectively – more than the total annual spending on maize- and wheat-breeding research in the developing world (Gollin, 2006).

Yield stability of improved varieties largely reflects long-standing efforts in breeding for disease and pest resistance. A third to a half of current R&D investments in crop breeding within the CGIAR may be for varietal maintenance. In one of the few studies to have attempted to capture this 'hidden impact' of CGI, Marasas et al. (2004) estimates that CIMMYT's work on maintaining leaf rust resistance alone has generated $5.4 billion in net present value for the period, 1973–2007. A more recent estimate by Dubin and Brennan (2009) puts the total benefits of resistance to all types of wheat rust at between US$600 million and US$2.0 billion per year globally, in 2006 dollars.

Since large areas of major food crops are now planted each year in relatively few improved varieties, genetic uniformity can make

[6] According to the Africa Rice Center's website, NERICA lines have been tested in 31 countries, with 16 lines released in 15 countries, and adoption on about 200,000 ha.

[7] Note, however, that other studies, which focused on direct productivity effects, did not find significant linkages between technology adoption and poverty reduction (see Adato and Meinzen-Dick, 2007).

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crops vulnerable to major yield losses. There is some evidence that genetic uniformity increases yield risk, even though it can also produce higher average yields (Smale and Drucker, 2007). In recent decades the world has largely avoided major disasters from genetic uniformity, in part because more frequent turnover of varieties has brought new sources of resistance. However, the emergence of a new race of stem rust in wheat after over 50 years has found CIMMYT, ICARDA and their partners scrambling to find and release a new generation of resistant varieties (Stokstad, 2007). Likewise IITA has successfully tackled a severe outbreak of cassava mosaic disease in western Kenya via rapid identification and release of resistant varieties (Abele et al., 2005). Quantitative assessment of the impacts of these activities remains a promising but unresearched endeavor.

Biofortification for improved nutrition

Recent evaluation of biofortified crops is interesting in that it is one of the first examples within the CGIAR of using experimental approaches to evaluate interventions – specifically, comparison of a biofortified treatment versus a conventional variety in randomly selected households.[8] Quality protein maize (QPM), which is now grown on about 600,000 ha, has been subject to a number of such evaluations – although none without methodological problems. In a meta-analysis of nine such studies, Gunaratna et al. (2010) found an average effect of QPM on rate of height gain of 9% and on weight of 12% for infants and young children with mild to moderate under-nutrition from populations in which maize is the major staple food. In Mozambique, 850 households participated in an experiment with orange-fleshed sweet potatoes. Significantly increased intake of vitamin A was measured among young children when households receiving the orange-fleshed treatment combined with extension advice on nutrition (Low et al., 2007).

These studies are not in strict sense impact studies, since they do not consider aggregate adoption and long run use. Still, this type of work is likely to accelerate with the scaling up of biofortification research under the Harvest Plus program. *Ex ante* impact work is also underway. Stein et al., (2008) evaluated the potential impacts on disability adjusted life years (DALYs) of Vitamin A rice in India; and Meenakshi et al. (2009) evaluated the potential net benefits of a biofortification with provitamin A, iron, and zince of a variety of staple foods in Africa, Asia, and Latin America.

Summary assessment

Crop genetic improvement has long been the staple activity of the CGIAR, one whose net benefits have been very large and very well-chronicled. Overall, the available evidence indicates continuing benefits and a large and varied pipeline of technology products flowing out of the CGIAR's CGI research – despite ever tighter funding. However, given the long lags between initial funding and technology adoption, it remains to be seen whether or not the decline in the share of funding for CGI will compromise the flow of net benefits over the long term. Finally, investments in CGI for several orphan crops have been found to produce impressive gains in local and regional analyses, but most have yet to be comprehensively evaluated in the quantitatively rigorous way that other crops were in the landmark Evenson–Gollin volume. Finally, it should be noted that a striking gap exists in our understanding of the *ex post* impacts of CGI research on the environment (as noted, for example, by Hazell, 2009).

[8] Diagne (2006) and Rusike et al. (2010) also employ modern evaluation techniques to estimate local average treatment effects against a matched set of households for NERICA adoption in Cote d'Ivoire and improved cassava adoption in Malawi, respectively.

Pest management research

Many CGIAR Centers have invested considerably in pest control, focusing on biological control, integrated pest management (IPM), and resistant varieties (the last discussed above under CGI). Of these, the impacts of IITA's biological control have been particularly well-documented. One of the best known cases is the control of the cassava mealybug in 20 countries of sub-Saharan Africa (Zeddies et al., 2000). The biological control provided by an introduced wasp was so effective that the cassava mealybug is now largely contained. Even when using the most conservative assumptions, the return on this research investment has been extremely high (net present value estimated at US$9 billion).

Biological control has since been extended to cassava green mite, mango mealybug, and water hyacinth (Coulibaly et al., 2004). Evaluations consistently show very high returns to the investments in these programs. Indeed biological control makes up a large share of the demonstrated benefits of the CGIAR's research portfolio in sub-Saharan Africa (Maredia and Raitzer, 2006). Coulibaly et al. (2004) estimates investments in biological control of cassava mealy bug to have generated net present values of US$1.7 billion for Nigeria, US$383 million for Ghana, and US$74 million for Bénin. And even these impressive benefits are likely understated, because the analyses did not account for ecological benefits against the counterfactual of increased use of chemical pest control.

Although there has been considerable investments in IPM approaches especially using farmer field schools to train farmers, there are few studies to rigorously quantifying impacts. And of those that have, most have not demonstrated the expected cost-effectiveness of these field schools (Feder et al., 2004). This is in part because complex management information, such as that for integrated pest management, does not travel as easily from farmer to farmer as in the case of seed of improved varieties (Tripp et al., 2005).

On the other hand, a study that assessed CIP's pilot field school program in Peru found a 14-percentage-point increase in knowledge score for participants and an estimated gain in productivity of 32% (Godtland et al., 2004). And a project in Vietnam called "Three Reductions Three Gains" begun by IRRI in 2003 has demonstrated the value of diffusing information about the benefits of reducing pesticide use, and lowering fertilizer use and seeding rates. This project uses radio and TV dramas, in addition to more traditional extension channels, to achieve partial or relatively complete adoption by about half of farmers, with an average of about 10% reduction in unit production costs in two of the three provinces surveyed; impacts were not significant in a third province (Huelgas and Templeton, 2008).

Finally, policy-oriented research by Templeton and Jamora (2007) to be described below provides evidence of large impacts of IRRI research led by Rola and Pingali (1993) on the health costs of pesticide use. The value of private health savings from that research – attributable to regulation of highly toxic insecticides in rice production, labeling requirements, and training of rural health officers – has been estimated to have a net present value of $117 million.

Natural resource management research

Natural resource management (NRM) research within the CGIAR has evolved substantially over time. The decision in 1990 to expand the CGIAR to include four new Centers with mandates in forestry (CIFOR), agroforestry (World Agroforestry Center), water management (IWMI), and fisheries (WorldFish Center) marked a turning point in the position of NRM research within

Table 5
Natural resource management resource impact studies.

Center (timing)	Location (scale[a])	Project type	Investment	Qualitative impacts	Quantitative impacts
CIAT (1993–2004)	Thailand Vietnam (A: eight villages)	Cassava productivity enhancement, soil conservation, farmer participatory research	$4.0 million	Knowledge, institutional learning	2802 additional tons of cassava per village IRR = 34–41%
CIFOR (1994–1999)	Global (P: 45 million ha)	Criteria and indicators of sustainable forest management in forest policymaking.	$3.3 million	Cost savings for certifiers of sustainable forest management	Not reported (policy study)
CIMMYT (1990-ongoing)	India (A: 0.82 million ha, P: 3.43 million ha)	Zero-tillage in rice–wheat systems	$3.5 million	Conservation of water and energy resources, soil quality improvement	NPV = $94–164 million $39 < b/c < 68$ IRR = 57–66%
ICARDA (1995–2002)	Morocco (A:1650 ha, P: 350,000 ha) Tunisia (A: 470 ha, P: 96,000 ha)	Alley cropping in mixed crop livestock systems	<$1.0 million	Reduction of soil erosion; net environmental benefits = US$31 per hectare	Morocco: IRR = 48% Tunisia: IRR = 16%
World Agroforestry Center (1986–2002)	Zambia (A: 77,000 farmers)	Tree fallows in maize	~$3.5 million	Carbon sequestration, risk reduction, reduced soil erosion	NPV = $2–20 million IRR = 3.2–20.8%
IWMI (1992-ongoing)	South and Central Asia (A: 50,000 downloads, 7500 copies of IMT guidelines	Irrigation management transfer	Not reported	Demands for policy advice	Not reported (policy study)
WorldFish (1986 – mid 1990s)	Malawi (A: 1000 t of fish per year P: 15,000 t of fish per year)	Integrated agriculture–aquaculture with farmer participatory component	$1.5 million	Improved household nutrition	NPV = $3.1–3.5 million $1.37 < b/c < 1.56$ IRR = 12–13%

Sources (in order): Dalton et al. (2007), Spilsbury (2007), Laxmi et al. (2007), Shideed et al. (2007), Ajayi et al. (2007), Giordano et al. (2007) and Dey et al. (2007).
[a] *A* = actual, *P* = predicted.

the System. Investments in those four Centers grew steadily throughout the 1990s and into the 21st Century – in part at the expense of commodity and eco-regional Centers with a stronger productivity-enhancement orientation (Kelley et al., 2008). This was also the case for allocation of resources to natural resource management programs *vis-à-vis* other programs within the other Centers. At the same time, however, there have been persistent concerns raised about the dearth of studies assessing the impact NRM research, most notably in the finding that NRM research is "under-evaluated" by the World Bank's 2003 meta-evaluation of the CGIAR (World Bank, 2003).

In response to this critique – and to increasing requests for evidence of payoffs to NRM research by donors – SPIA commissioned (in 2003) a set of seven case studies of research projects that were initiated in the mid-1980s or early 1990s (Waibel and Zilberman, 2007). At the time of analysis, 5–10 years had elapsed since those projects' completion – time enough, so it was judged, to make reasonable inferences about likely diffusion paths. Table 5 summarizes the seven case studies. Five were micro-level, commodity-oriented projects whose aggregate impacts were estimated from observed farm-level impacts and projected diffusion paths. The other two studies (conducted by CIFOR and IWMI) focused on macro-level research geared toward informing NRM policy at the regional or national level.

With the exception of zero-tillage packages in South Asia's rice–wheat systems, the micro-level NRM research activities and the crop management packages they produced were rather location-specific. This distinctly limited the geographic scale over which these innovations could be projected to spread. Unfortunately, and in most circumstances unavoidably, this limits the ability of much NRM research to generate international public goods – a challenge that was identified in the 2003 World Bank meta-evaluation (World Bank, 2003). On the other hand, it can be argued that the methods used in NRM research are themselves international public goods. However, we were not able to find evidence documenting the welfare impacts of such methodological spillovers.

The estimated internal rates of returns (IRRs) for the micro studies ranged from 3% to 66% (Table 5). These are comparable to IRRs typically found for many agricultural innovations, and indicate clear payoffs to NRM research (at least for this particular set of case studies).[9] They were not, however, as high as rates of return for CGIAR crop genetic improvement research noted above. On the other hand, most of the micro-level case studies did not account for environmental benefits due to the difficulty of quantifying them. Rather, the estimated benefits were confined to production impacts. Underestimating the true benefits in this way almost certainly biases downward the estimated rates of return and benefit-cost ratios.

Compared to embodied technologies like improved seeds, complementary investments in extension, collective action and local institutions governing property rights generally play a more prominent role in facilitating the adoption of the knowledge- and management-intensive NRM technology products. Indeed, much NRM research is attentive to how best to cultivate a supportive institutional environment. Still, this aspect of NRM technology packages, coupled with weak institutional capacity in the study locations, meant that the projects' outreach components were critical to their having significant positive impacts.

The benefits described in the two macro-level policy studies listed in Table 5 (sustainable forest certification and devolving irri-

[9] The case studies were selected on the basis of a competitive process, as opposed to a representative sampling of NRM research activities.

Table 6
Impact assessment of policy-oriented research in the CGIAR.

Center (timing)	Location (scale)	Program assessed	Qualitative impacts	Quantitative assessment
IFPRI (1995–1997)	Vietnam (all rice consumers and producers)	Research on liberalization of rice prices toward export parity	Relaxation of rice export quotas and internal restrictions on rice trade	NPV of total benefits = $45–91 million 56 < *b*/*c* < 114
IFPRI (1991–2003)	Bangladesh (17,811 schools, 2.1 million students)	Food for education program	20–30% increase in school participation rates. IFPRI influenced (a) program conception, (b) program evaluation, (c) improved program targeting, and (d) training and capacity building.	NPV of total benefits = $248 million IRR = 64–96%
IFPRI (1992–2000)	Bangladesh (all consumers)	Rural rationing program	Abolishment of the program; promotion of private tendering of food; lowered food prices; downward adjustment of food stocks	Median NPV of total benefit = $41.1 million 11.7 < *b*/*c* < 60 Median IRR = 98%
CIFOR (2000–2006)	Indonesia (107,000 ha conserved, 32,000–76,0000 ha not cleared	Political economy of the pulp and paper sector, fiber sourcing practices	Improvements in sustainability of pulp production practices, regulation of the pulp and paper sector, and due diligence for forestry investments	NPV of total benefit = $19–21 million 0.96 < *b*/*c* < 6.2
ICARDA (1984–2005)	Syria (1.5 million ha)	Fertilizer distribution/ pricing policy for barley in arid zones	Increased barley output, improved livestock nutrition due to more efficient fertilizer use	NPV of total benefits = $73.4 million *b*/*c* = 41 IRR = 70.2%
ILRI (1996–2004)	Kenya (all milk consumers and producers)	Decriminalization of marketing by small-scale milk vendors	Reduced marketing margins, increases in both consumer and producer surplus	NPV of total benefits = $44–283 million IRR = 62–108%
IFPRI (1997–2000)	Mexico (5 million families)	Monitoring and evaluation of *PROGRESA* program of conditional cash transfers	(a) Faster program implementation; (b) improved program evaluation and project manager training; (c) enhanced likelihood of program continuation beyond political regime changes; (d) spillovers to programs in other countries	Median NPV of total benefits = $992/ student (a) *b*/*c* = 16.4 (b) *b*/*c* = 5.8 (c) *b*/*c* = 57.1 (d) *b*/*c* = 4.9
IRRI (1989–2018)	Philippines (90% of Philippine rice area, 80% of rice farmers	Private health cost savings of pesticide use policies	Regulation of highly toxic insecticides in rice production; labeling requirements; and training of rural health officers	NPV of realized benefit = $117 million *b*/*c* = 98; IRR = 65%

Sources (in order): Ryan (1999), Ryan and Meng (2004), Babu (2000); Raitzer (2008), Shideed et al. (2008), Kaitibie et al. (2007), Behrman (2007) and Templeton and Jamora (2007).

gation systems management to users) were much more qualitative in nature due to difficulties in attribution of research impacts to the specific research outputs (i.e., contributions to knowledge). Analysis was confined to documenting impact pathways, as opposed to measuring specific impacts. These issues are common to many, perhaps most, policy-oriented research activities (discussed in the next section).

In sum, the limited available evidence suggests positive returns on investments in a variety of NRM research activities within the System; but *measured* benefits to date have not yet justified the large investments in this area. As methods for measuring impacts of NRM research become increasingly well-developed, documentation of benefits should accelerate. However, much NRM research is constrained by weak institutional support systems. Moreover, NRM work typically deals with systems, rather than components to a greater degree than other types of CGIAR research (particularly CGI). Both of these factors increase the location specificity of NRM research, and probably limit the international public good dimensions compared with CGI research.

It bears repeating that NRM research impact assessments to date have focused exclusively on productivity benefits and largely have ignored environmental benefits, presumably because of the methodological difficulties in quantifying them. Application of the non-market valuation techniques required to measure these benefits remains relatively rare in developing country contexts. A consequence of this is that there is little evidence on the success or failure of the CGIAR in meeting its goal of promoting environmental sustainability. One exception to this broad generalization is the comprehensive environmental valuation of impacts of CIFOR policy research by Raitzer (2008) who estimated non-market benefits of watershed services, carbon sequestration and biodiversity preservation through avoided deforestation in Indonesia.

Policy-oriented research

Policy analysis is the primary mandate of four Centers (IFPRI, IWMI, CIFOR, and Bioversity) and is a major focus, to varying degrees, of all of the others. CGIAR expenditures on policy-oriented research (POR) have grown substantially over time, both in absolute terms and as a fraction of the System-wide research portfolio.[10] Conservative estimates place the total value of CGIAR investment in POR from 1971 to 2004 at $800 million in real (2004) terms, and more than triple that number using a broader definition of policy research (Raitzer and Ryan, 2008).

As with NRM research, the World Bank's (2003) meta-evaluation of the CGIAR found a striking lack of credible studies analyzing impacts of the large historical investments in POR. To fill this gap, SPIA identified and reviewed 24 *ex post* assessments of CGIAR POR

[10] Using data from CGIAR annual reports, Havenner computes that overall funding for policy grew by roughly 85% between the early 1992 and 2005 – from 10% to 16.5% of the total System-wide budget. During the same period, production-related fell by 15%, from nearly half to just over one-third of the System-wide budget (Art Havenner, pers. comm.).

projects (SPIA, 2006). Only three of these 24 studies yielded empirical estimates of economic impacts, all from IFPRI. Two evaluated poverty related programs in Bangladesh and one evaluated impacts of research on changes in rice price policies in Vietnam (Table 6). About half of the others (10/21) documented "influences," generally relying on interviews of relevant stakeholders as "data."

The studies spanned a range of policy domains: property rights, plant genetic resources, and gender. These provide substantial qualitative evidence on how and why POR and the recommendations it generates find their way into the real-world policy formulation and implementation. But most studies stop well short of quantifying impacts on the CGIAR core missions of food security, poverty reduction, and environmental sustainability.

The dearth of empirical impact assessments is attributable to the very difficult challenges facing analysts of POR, both in the quantification of ideas and knowledge – the fundamental products of POR – and their attribution to specific producers of that knowledge. As a follow-up seven POR Impact Assessments were commissioned by SPIA in 2007 to augment available studies from IFPRI. These studies review a wide range of policy interventions—forestry, fertilizer, conditional cash transfers, milk marketing, and pesticide policy (Table 6).

The estimated net benefits of each of these policy research projects were in the tens or hundreds of millions of dollars in net present value – substantial, but well below those attributed to CGI and biological control research successes. And all studies found substantial internal rates of return and/or benefit-cost ratios. Walker et al. (2008b, p. 88) note that the impressively high returns on specific POR projects reflect to a large degree the relatively short gestation period of POR along with a compressed diffusion process.

A few additional observations to these positive results are in order. First, the studies employed different means of estimating the contribution of a specific Center's research to policy formulation and/or implementation, as well as attributing behavioral changes of various economic agents to the altered policy environment. All studies indicated that "conservative" assumptions were made in this regard, although defining what constitutes conservatism in this context is inevitably *ad hoc*. But importantly, if we take as given that the authors of these studies have erred on the side of caution, then the true net benefits of POR are larger – perhaps substantially so – than what have been reported.

Second, identification of the appropriate counterfactual – what would have occurred in the absence of the research that was conducted – is a difficult challenge for assessing POR impacts. In most cases, the counterfactual related to earlier and/or more rapid implementation of a policy or set of actions than would have occurred without the Center's involvement. Again, there is little if any obvious guidance available in the impact assessment literature to assist in making these choices. As with attribution issues, the analysts tended to simply adopt "conservative" assumptions, presumably in the hope that any bias in the benefits estimation would be downward. This is not meant to call into question the accuracy of the studies' qualitative findings, but rather to point out the inevitable lack of precision in the point estimates of economic impact.

Third, all of the impact assessments listed in Table 6 were country studies conducted within a particular, country-specific policy environment. Most produced knowledge potentially relevant to policy domains in other countries. Documentation of such spillovers is quite difficult, however, particularly given the sporadic, "right-time, right-place" nature of policy changes. Only two studies – Behrman's (2007) analysis of IFPRI's contribution to Mexico's conditional cash transfers program and Ryan's (1999) analysis of IFPRI's contribution to policy change in Vietnam's rice sector – quantified this international public good element of policy research. Both studies found that the value of these spillovers alone exceeded the projects' costs.[11]

In a similar vein, it is likely that some of the CGIAR's policy research has been extremely influential in setting the global policy agenda, even though it cannot be readily quantified in terms of development goals of income generation and poverty reduction. Examples include the bioversity's role in successfully concluding the International Treaty on Plant Genetic Resources (Gotor, 2008), and the influence of IFPRIs research on international trade liberalization and the Doha trade negotiations (Hewitt, 2008).

Finally, the sum of estimated net benefits from the studies listed in Table 6 still falls short of the CGIAR's total cumulative investment in policy-oriented research (Walker et al., 2008b). That these studies represent only a subset – albeit a highly successful subset – of POR conducted within the System underscores the need for further documentation of other POR impacts in order to justify the large (and increasing) amount of resources invested in CGIAR policy research over the past twenty years.

Meta-reviews at the global and regional levels

Three studies published in the past six years have quantified the impacts of the CGIAR as a whole at a global level (Raitzer and Kelley, 2008) and in the two regions with the largest number of poor people – sub-Saharan Africa (Maredia and Raitzer, 2006) and South Asia (Hazell, 2009). By aggregating benefits from impact studies and comparing them against total costs of the CGIAR System, these meta-analyses overcome the potential bias of "cherry picking" of successful impact cases for impact evaluation. All of these studies have found that the benefits from past investments in CGIAR research activities have exceeded the costs of that research, in most cases by a large margin – an important benchmark, albeit one that needs to be coupled with impact analyses of the specific research areas in order to address questions of immediate interest to investors.

Raitzer and Kelley (2008) provide the only comprehensive assessment of the relative benefits and costs of CGIAR research investments over the System's lifetime. This meta-analysis reviewed all available *ex post* impact assessments found in peer-reviewed journal articles, book chapters and Center publications to come up with estimates of the total benefits attributable to the CGIAR. It considered only studies that were published after 1989, covered middle- or low-income countries, and generated total benefits exceeding $50 million. A rating scale was developed – based on the transparency of analytical methods, the extent to which causality was demonstrated, plausibility of counterfactuals, and degree to which estimated impacts were projected beyond the time frame analyzed – to establish a range of estimated benefits.

Estimated System-wide benefits ranged from nearly $14 billion to over $120 billion in net present value (Fig. 1). The benefit-cost ratios suggest that investments in the CGIAR have paid for themselves by a wide margin. Even by the most conservative criterion, overall benefits attributable to CGIAR research were roughly double the costs of total investment in the System. Moreover, the very small number of extant impact assessments of natural resource management and policy-oriented research at the time that the study was conducted meant that the true benefits of CGIAR research were understated, insofar as evidence presented above suggests that these lines of research also have had sizeable positive impacts. Coupled with the fact that all System-wide expenditures

[11] In addition, a very recent study by Behrman and Calderon (2009) documents substantial influences of IFPRI evaluations of a number of conditional and non-conditional cash transfer programs on the design and sustainability of transfer programs in which IFPRI did not directly participate.

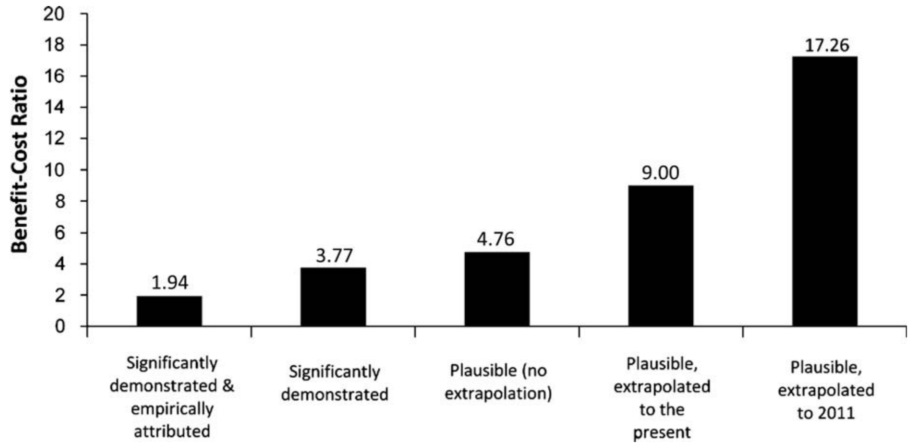

Fig. 1. Aggregate benefit-cost ratios of CGIAR research under different scenarios of study selection.

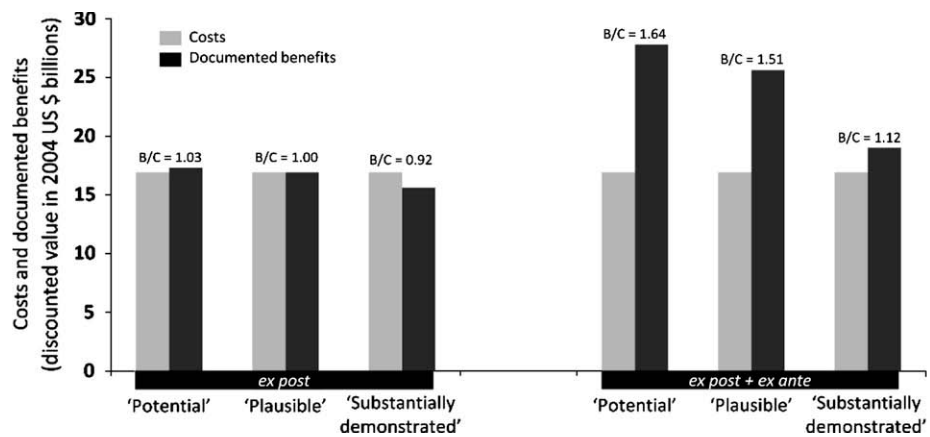

Fig. 2. Comparison of calculated costs and estimated benefits of joint CGIAR-NARS investments in sub-Saharan Africa.

were considered, the reported benefit-cost ratios were correspondingly understated.

Also of note, a very large proportion of overall benefits were associated with just a few of the CGIAR's many programs. Roughly half (47%) of total benefits were attributed to rice breeding, and an additional 31% were attributed to wheat breading. Bio-control of the cassava mealybug accounted and maize accounted for most of the remaining total benefits.

Sub-Saharan Africa

Since its founding in 1971, the CGIAR has invested approximately $4.3 billion in sub-Saharan Africa (Maredia and Raitzer, 2006). This represents 41% of total CGIAR expenditures, the largest share allocated to any geographical region. Coupled with the continent's relative lack of success in achieving agricultural development and poverty reduction goals, the scale of resources devoted to sub-Saharan Africa (SSA) has inevitably raised questions regarding the returns on those investments.

Following similar methods to those described for the System-wide evaluation, Maredia and Raitzer (2006) undertook a meta-analysis of 22 impact assessment studies conducted in SSA. The final set of studies considered was culled from a much larger group of 367 studies that were initially reviewed. Primary criteria for inclusion of a study in the meta-analysis included a sufficiently large geographic scale of adoption (eliminating a large number of small-scale adoption studies); quantification of research benefits; and having undergone a peer review. Nearly all of the studies that emerged from this screening process evaluated either crop genetic improvement or biological control technologies.

Benefits exceeded costs for all scenarios that included *ex ante* projections beyond the study period, with benefit-cost ratios ranging from 1.12 to 1.64 (Fig. 2). When only *ex post* benefits were considered, benefits and costs were much more evenly balanced; for the most conservative scenario, costs slightly outweighed benefits. Yet even if benefit-cost ratios rise to the level of the least conservative scenarios that project future benefits, they would have been well below those found in the System-wide meta-analysis. Thus, while the aggregate benefits from CGIAR research investments in SSA have almost certainly exceeded their costs, the returns to those investments have been considerably lower than in other parts of the world.

The geographic scale of measured impacts is also relatively small. As of 2000 only about 11 million ha (out of about 100 million ha) were planted to CGIAR-derived improved germplasm in SSA (Maredia and Raitzer, 2006, p. 18). And beyond improved varieties and biological control, adoption of specific CGIAR technology products was fairly small-scale (in the tens of thousands of hectares). Note, however, that the very recent studies of impacts of CGI for maize, beans, cowpeas, and rice in Africa discussed above would substantially increase the impact of CGI in Africa.

South Asia

Hazell (2009) recently undertook a review of agricultural investments by the CGIAR and its partners in South Asia in the post-Green Revolution period (i.e., since the early 1980s). The study takes a less structured approach to impact assessment than the two meta-analyses just described, reviewing existing peer-reviewed studies of productivity, social, environmental, and policy impacts.

Hazell summarizes a large body of evidence indicating that agricultural research in South Asia has been instrumental in maintaining impressive rates of agricultural productivity growth in the region in the post-Green Revolution period, and that these have yielded substantial indirect impacts on food security and poverty reduction via price effects. CGIAR Centers have made particularly impressive contributions to overall well-being via crop genetic improvement (CGI). Based on existing impact assessments, Hazell finds average annual benefits of over $1 billion from CGI work, far in excess of the estimated $65 million of annual expenditures of the CGIAR in South Asia. Hazell also provides evidence of significant net benefits arising from work on efficient water and fertilizer use, on integrated pest management, and on zero-tillage. However, he also finds that there is a dearth of studies linking agricultural research investments to environmental or poverty impacts.

Synthesis and conclusions

This article has reviewed recent evidence on the impacts of CGIAR research published since 2000. Overall, our review suggests CGIAR research contributions in genetic improvement, pest management, natural resources management, and policy have, in the aggregate, yielded strongly positive impacts relative to investment. And on the basis of limited information on outcomes and impacts since 2001, they are likely to continue doing so.

A number of implications may be drawn as to how successful the CGIAR Centers have been in recent years in pursuing the core missions of the System – agricultural productivity, poverty reduction, food security, and environmental sustainability. Global and regional meta-evaluations suggest that CGIAR research has delivered positive impacts in a range of programmatic areas and across a range of regions. Globally, investments in the CGIAR have paid for themselves by a wide margin. Successes of crop genetic improvement have been most prominent in most regions. An exception is sub-Saharan Africa, where the evidence suggests that biological control research has been more important than CGI research, although the latter has shown notable successes in recent studies.

The subject breadth of CGIAR research has been important to the System's observed level of success, as indicated by regional differences in relative impacts of different types of research. Real world outcomes from particular research endeavors are inevitably uncertain, no matter how promising the research might have appeared in the lab or the experiment station; hence the desirability of a wide-ranging portfolio of investments from the perspective of System-wide research resource allocation. Such a broad portfolio is more readily facilitated through stable long-term "core" funding than through "special" funding of specific projects by individual donors.

Crop genetic improvement research, historically the bread and butter of the CGIAR, stands out as having had the most profound documented positive impacts. In part, this is due to the fact that embodied technologies like improved seed varieties are tangible outputs whose impacts can be readily measured and attributed to the efforts of the Centers and their national partners. Nonetheless, the direct productivity impacts and indirect (wage and price) impacts of yield-enhancing and yield-stabilizing modern varieties produced by the Centers and their partners at the national level have been – and continue to be – very large, generating profound benefits to poor people both within and outside the agricultural sector. There is thus a strong case to be made for continued and increased System-wide investment in CGI research.

With respect to crop improvement research, one worrisome aspect is the paucity of evaluative evidence since the landmark Evenson–Gollin study. Emerging success stories in CGI – especially for maize, cowpeas, potatoes and beans in sub-Saharan Africa – have been found to produce impressive gains in local and regional analyses, but global impacts have yet to be comprehensively evaluated in a quantitatively rigorous way. This same critique applies to many promising products in the pipeline for which diffusion appears poised to "take off" (e.g., Vitamin A rice and submergence tolerant rice). Finally, the overwhelming focus of recent evaluation work has been on estimating rates of return from research investments; links between CGIAR investments and development goals of reducing poverty and hunger, promoting gender equality, and enhancing environmental sustainability have not been sufficiently and convincingly demonstrated.

Substantial evidence exists that other research areas within the CGIAR have had large beneficial impacts. Assessments of research on pest management reveal large positive impacts of biological control research (particularly in Africa), resistant varieties, and localized successes in integrated pest management. These studies are a bit dated, though, and there is less evidence of biological control or IPM research having similarly large impacts in recent years.

The recent emphasis within the CGIAR on assessing the impacts of natural resource management research and policy-oriented research will likely increase the pace at which the impacts of these activities are documented. However, we have noted that much NRM research occurs at a relatively limited geographic scale vis-à-vis other types of CGIAR research, often because institutional factors are central to adoption of NRM technologies. This probably limits the potential for spatial spillovers of management practices and biophysical packages, particularly in comparison to spillovers associated with seed varieties (although spillover potential of NRM research methods are potentially large).

Policy-oriented research offers significant potential for generating broad impacts affecting large numbers of people, and for generating knowledge relevant to policy domains in countries other than where the research takes place. Some good examples of empirically rigorous impact evaluation of successful POR have been highlighted here. But because knowledge and ideas are the fundamental product of this line of research, attribution of impacts and establishment of credible counterfactuals remains a formidable constraint to impact evaluation. Studies frequently resort to *ad hoc*, albeit well-reasoned, assumptions in order to quantify impacts. Also, some of the most profound impacts of policy research may be on the global policy agenda. Although CGIAR influence has been demonstrated in some studies it is extremely difficult to translate these 'influences' into more quantifiable measures of social and environmental impacts. Finally, policy research often generates ideas and knowledge whose translation into actionable impacts requires a sustained presence of researchers within the policy arena – not always feasible when project funding is time-limited and/or conducted by researchers who are not based in-country.

NRM and policy research are quintessential public goods justifying public funding (Dalrymple, 2008); indeed, a case can be made that the non-private share of total benefits in these research lines exceeds that of CGI. Yet identifying the *international* public good dimension of NRM and policy research has proven elusive in the impact evidence available. This suggests that relative to CGI, a higher share of the research in these areas should be funded at the national or regional level.

There has been much debate within the CGIAR about the relative balance of investment in CGI versus other research areas, particularly in an era of stagnating core contributions to international agricultural research. With respect to this debate, we would note first that it is not entirely appropriate to consider such research as "alternative" to CGI research. For instance, much NRM research in the CGIAR has its origins in efforts to secure and maintain the full benefits of crop genetic improvement – particularly if and when agricultural intensification is accompanied by environmental degradation. Hence, some NRM research benefits may be inseparable from CGI research benefits. This is also the case for pest management research, including biological control and IPM – the benefits of which have been substantial. Likewise, POR will be complementary to CGI if such research successfully contributes to a policy environment that facilitates more rapid technology adoption (e.g., by remediating input supply bottlenecks) or mitigates distortions that impede the transmission of price effects to consumers.

Whether impacts of NRM and policy research can ever approach those of CGI research is a debatable point given the limited quantitative evidence for the former. There continue to be large challenges to measuring the benefits of NRM and policy research, and so it is likely that considerable uncertainty on this point will persist into the future. From the evidence presented here, though, we believe it is reasonable to conclude that while NRM and policy research in the CGIAR remains under-evaluated, CGI research has nonetheless produced substantially larger net benefits.

Given these uncertainties and the very strong record of positive impact attributable to CGI, it would appear that the CGIAR's portfolio of research allocations has become overly skewed toward NRM and policy research over time. Thus, a move toward restoring somewhat the share of resources allocated to CGI would seem warranted. In fact, this seems to be happening as the Bill and Melinda Gates Foundation have sharply stepped up their funding of CGIAR research, mostly in the area of CGI, albeit still largely as restricted funding.[12]

Past success is of course, no guarantee of future impacts. Indeed, recent efforts to re-organize the System suggest that stakeholders perceive significant challenges to maintaining the level of success that the CGIAR has produced to date. Success in these reform efforts will require continuing assessment of the impacts of specific research programs, regardless of the institutional nexus within which those programs are arrayed. In particular, the CGIAR needs to prioritize impact assessment of resource management and policy research in order to deepen its understanding of the social and environmental impacts of its work.

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