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Review Article

Impacts of CGIAR Crop Improvement and Natural Resource Management Research: A Review of Evidence

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Abstract

This paper has examined the trends in funding and impacts of CGIAR research with a focus on distribution of economic benefits and sustainability of natural resources. The evidence has clearly shown that the impacts in terms of agricultural growth, poverty reduction and environmental protection continue to be impressive. The success of varietal development programmes mainly stems from free exchange of plant genetic resources and partnerships with NARSs. However, the impact of natural resource and production system management research has been site-specific. Its spread has been restricted because of policy and institutional constraints on transfer of technology.

Key words: Crop improvement, CGIAR research, NRM research, Poverty alleviation, Environmental protection, Agricultural growth

JEL Classification: Q56, Q58, Q18

Introduction

The CGIAR Centres in partnership with the national agricultural research systems (NARS), civil society organizations (CSOs), and other stakeholders are working together to overcome the problems of agriculture, especially in developing countries. All the Centres have generated a lot of research output to overcome numerous impediments in diverse agro-climatic and socio-economic environments. The degree of success that science in these Centres has achieved in fulfilling their missions, combined with the impact science has made on agriculture, welfare of rural population, poverty alleviation and environmental security in the developing world, are the key issues for studying the impact of CGIAR research.

A number of studies have deen done to measure the research impacts and it is important to draw major trends and lessons from these studies. A synthesis of such evidence is useful to understand perspectives, impacts and lessons for targeting of technology in future. For this review, one set of evidence consulted includes, *inter alia*, Centres' annual publications, evaluation studies and External Programme and Management Reviews (EPMRs). Another set of evidence consists of reports of the Standing Panel on Impact Assessment (SPIA) of the Science Council and studies conducted by various external agencies. Another important source of information is individual CGIAR member-commissioned evaluations (e.g., World Bank-OED Meta Evaluation and other donor-supported studies). The scope of the review is limited to the studies published during the past one decade or so. However, in some instances, inferences have also been based on the past work to get insight on the benefits accruing through upscaling or maintenance research.

The paper first provides an overview of the system's expenditure and its broad allocations, followed by economic impact of crop improvement research. The next section deals with impacts of natural resource

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management research. Research impacts on environmental protection and poverty alleviation are also discussed. The paper concludes with some observations on measures to enhance research impacts.

Trends in Research Expenditure

More than 8,500 researchers drawn from various disciplines and fields of specialization staff 15 CGIAR Centres located in different parts of the globe. The CGIAR system has spent 7,686 million US dollars since its inception in 1971. The Members contributed most of these funds. In 2006, annual funding was of 426 million USD against 357 million USD in 2002. Funding from the members is either unrestricted with flexibility in its allocation, or restricted to specific programmes, region or activities. In 2006, share of unrestricted funding in the total funding was 42 per cent, which is slightly lower than that in recent few years.[1]

Regional expenditure pattern shows that 48 per cent of the total expenditure was on research programmes for sub-Saharan Africa (SSA), which is justified because of high incidence of poverty, low productivity and weak national research system in the region. Asia-focused research programmes received 29 per cent of the resources, while 14 per cent were spent on Latin America and the Caribbean (LAC), and the remaining nine per cent were spent on Central and West Asia and North Africa (CWANA). This pattern has been consistent since 2000, except marginal increase in resources for SSA at the cost of Asia and LAC (Figure 1). Annual expenditure across the Centres has varied considerably. It was in the range of US$ 35-46 million for five Centres (CIAT, CIMMYT, ICRISAT, IFPRI and IITA), whereas it was US$ 20-35 million for other seven Centres in 2006. The expenditure for the remaining three Centres was US$ 11-16 million.

Long-term trends in CGIAR funding reveal some further insights. First, funding has not been equal to increase in number of Centres, especially in the 1990s, resulting a decline in funding for few Centres and some of these were founding Centres. Another change has been an increase in the share of restricted funding mainly because of increase in number of donors and their influence on setting research agenda. For instance, in recent years, increasing proportion of World Bank funding was restricted to research for global public goods and system-wide initiatives (Alston *et al*., 2006). However, research programmes for SSA and Asia continued to get most of the funding.

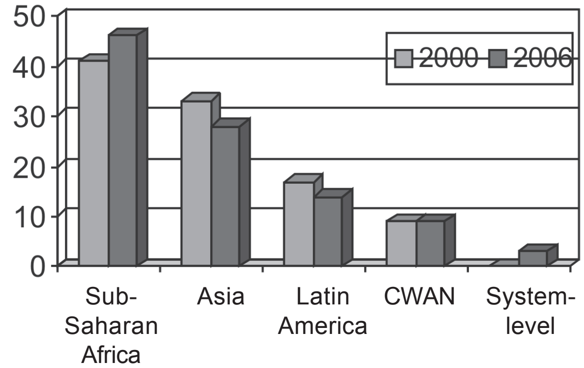

Figure 1. Per cent allocation of CGIAR expenditure by region
Source: CGIAR Annual Reports

Changes in research priorities and strategies have influenced resource allocation. Initially, much of the resources were for food crop research. This gradually declined, particularly for cereals which now account for less than one-third of the resources, down from more than 50 per cent in the 1970s. Also, improvement of plant genetic resources, which was the main research strategy during the earlier years of CGIAR existence, gradually got diluted by the programmes for enhancing sustainability of production systems, resources (water, land and biodiversity), environment, nutrition, and so on. New policy-oriented research accounts for nearly one-fifth of research resources (World Bank, 2003; CGIAR, 2006). Part of this change could be attributed to importance assigned by the stakeholders to these development objectives, but shifting focus of donors' funding was also responsible for increasing importance of sustainability enhancing-research in the CG system.

Impacts of Early Research

Major impact of CGIAR system during the green revolution period was realized through crop improvement research, especially the varieties bred by CIMMYT and IRRI. A good amount of efforts were made by social science program of CIMMYT to trace spread and impacts of their genetic material to different

[1]The expenditure data for recent years were taken from CGIAR Financial Report 2006.

parts of the globe (Byerlee and Traxler, 1995). This was further updated and extended to other crops, notably rice, sorghum, etc. (Pingali and Hossain, 1998). These gains were mostly realized in Asia and Latin America. Most significant research impact realized in Africa was through control of cassava mealybug (*Phenacoccus manihoti*) by use of a bio-control agent (*Apoanagyrus lopezi*) (Zeddies *et al*., 2001). These mega impacts are widely acclaimed and documented. There were some other studies done during the post-green revolution period and their results were used by different expert groups and analysts. The most important among these are a meta-evaluation of CGIAR system by the Operations Evaluation Department of the World Bank (2003) which recognized high returns to crop genetic improvement (CGI) research done by various Centres. The studies reviewed in this evaluation showed the rates of returns ranging from 40 to 78 per cent, which were considered to be well above the returns attainable from many alternative uses of public resources. This is mainly because CGI research constituted long-term investment programme with potential to increase productivity, generate spillover effects and exploit economies of scale (Gardner, 2002).

In another meta-evaluation of CGIAR impact (Raitzer and Kelley, 2008), all important studies covering impacts of CGI, biological control of cassava mealybug and other research were considered. The study covered the period 1960 to 2001 (including pre-CGIAR research) and estimated benefits under different scenarios based on the degree to which causality between research efforts and impact was demonstrated, transparency in data and methodology, comprehensiveness of the study, institutional attribution, and so on. The estimated benefit-to-cost ratio was 1.94 when the studies that "significantly" demonstrated research impacts were considered. The ratio improved to 4.76 when the "plausible" scenario of extrapolating the results up to 2001 was considered. The ratio further rose to 17.26 when extrapolation was done through 2011. The estimated internal rate of return (IRR) was 34 per cent. It is interesting to note that most of these benefits, say 93 per cent under the "plausible" scenario, were generated by three research programmes: (a) breeding of spring bread wheat (from CIMMYT); (b) modern rice varieties (from IRRI); and (c) cassava mealybug biocontrol (from IITA) (Figure 2).

These studies clearly established that research conducted at CGIAR made significant contributions in terms of increasing crop productivity and thereby ensuring food security in developing countries. Some of these technologies are still on farmers' fields and continue to generate substantial benefits. Some technologies or associated concepts were applied to other crops and most notable among these are use of green revolution varieties in plant breeding programmes and application of bio-control methods for management of diseases and insect pests of field crops. The question now arises that how the benefits of recently developed technologies compare with these meta impacts of the past research. This question is addressed in the next section.

Impacts of Crop Improvement Research

Although improvement of crop genetic resources and associated management practices received comparatively less resources during the recent period, its outputs and impacts are still widespread and dominant. The studies revealed that NARS in Asia,

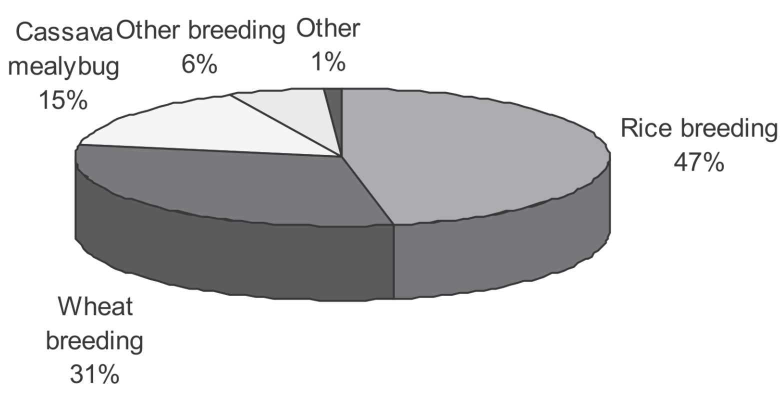

Figure 2. Percentage of benefits derived from different research areas in the scenario of "Plausible" studies

Source: Raitzer and Kelley (2008)

Africa and Latin America were able to develop a large number of varities based on crosses or parental lines developed by CG Centres. As seen from Table 1, number of varieties developed increased substantially during the 1990s over those developed in the 1970s and 1980s. Most of these varieties were developed in Latin America, Asia and Middle East and North Africa (MENA). More than 39 per cent of the varieties released during 1965-1998 in Latin America, SSA and MENA were purely based on CGIAR crosses. The share of such varieties was only 18 per cent in Asia. In addition, CG material was used as a parent for developing 14-22 per cent of the varieties in different regions.

The estimated IRR of plant breeding programs varied from 39 per cent for Latin America to 165 per cent for MENA. The established counterfactuals are equally revealing. In the absence of growth in crop productivity, food production in developing countries would have been lower by 7 to 8 per cent, prices would have risen by 18 to 21 per cent and additional 15 million children would have remained malnourished (Evenson and Rosegrant, 2003). All these projections have been made based on the technologies adopted prior to 2001. Similar projections during post-2001 are yet to be undertaken.

Although the macro analysis does testify to an impressive impact of CGI research conducted by various CGIAR centres, there are some micro realities indicating lop-sided progress. The successful CGI programmes were confined to rice, wheat and maize. These three crops accounted for two-thirds of the varieties released during the 1990s. Other important crops benefitted were sorghum, beans, cassava and potatoes. There was, however, little progress for other food crops, particularly in Africa. It was after some fumbling and learning that CGI for millets and other crops progressed. These were mostly grown in marginal agro-climatic conditions. In fact, in MENA and SSA, spread of modern varieties was limited because of several constraints on input delivery, technology transfer, infrastructure, policy, marketing, and so on (Maredia and Raitzer, 2006). On the other hand, countries such as India and China did better on these accounts largely because they could realize greater technology spillovers to generate substantial production and productivity benefits. For instance, annual benefits from rice research were about 20 per cent of the national rice production during 1980s and 1990s in China and India. Using some assumption about rice-variety ancestors, 1.7 to 6.8 per cent of the benefits in China and 18.1 to 56.4 per cent in India during 1991 to 2000 could be attributed to IRRI's research (Fan *et al*., 2007).

The data used by the studies reviewed here are prior to 2001, and projected impact of improved technologies developed by different Centres. As stated

Table 1. Average annual variety release for all crops by region and their IARC content

Particulars	Latin America	Asia	Middle East and North Africa	Sub-Saharan Africa	All regions
Average annual variety release for all crops, number					
1971-75	55.9	59.6	8.0	18.0	132.0
1981-85	92.5	86.3	12.2	43.2	240.2
1991-95	177.3	81.2	30.5	50.1	351.7
1996-98	139.2	79.9	82.2	55.2	320.5
Proportion of IARC content (1965-1998)					
Variety based on IARC cross (IX)	0.39	0.18	0.62	0.45	0.36
Variety based on NARS cross with at least one IARC parent (IP)	0.14	0.29	0.22	0.21	0.20
Variety based on NARS cross with at least one non-parent IARC ancestors (IA)	0.04	0.10	0.04	0.07	0.06
Variety based on NARS cross with no IARC ancestors (IN)	0.43	0.43	0.12	0.27	0.42
IRR (%)for IARC	39	115	165	68	NA

Source: Chapters 21&22 in Evenson and Gollin (2003) earlier, such studies are not available in the post-2001 period. It is high time to sponsor such macro-level studies, especially when the world has recently faced food crises. A case of declining funding to CGIAR and global food crises (especially rice and wheat) would attract donor attention to contribute more to increase global food production through sustained R&D efforts. The post-2001 studies on impact show relatively higher benefits from CGI than other research (e.g., natural resource management and policy research) done in different CGIAR Centres. With some exception, most of the studies during post-2001 provided micro-level evidence. Results of important impact assessment studies among these are discussed below.

Crop-specific impacts of improved genetic improvement research revealed large gains in productivity and higher rates of returns. For example, modern wheat and maize varieties from CIMMYT showed higher yields than farmers' traditional varieties. Modern wheat and maize varieties also reduced exposure of producers to risk. The available estimates showed that nearly 95 per cent of wheat area in the developing world was under improved varieties and nearly 65 per cent have CIMMYT germplasm. It was projected that added amount of wheat produced in developing countries and attributable to wheat breeding research was 14-41 million tonnes. It has been reported that the benefits from wheat breeding research were about US$ 2-6.1 billion (2002) on an annual and recurring basis and the benefits attributable to CIMMYT research were in the order of US$ 0.5-1.5 billion.

In the case of maize, annual benefits due to germplasm improvement research were in the range of US$ 668 million to 2 billion and the benefits attributable to CIMMYT research were US$ 557-770 million, depending upon the extent of CIMMYT material used in different programmes (Table 2). The benefits from maize research due to risk reduction were about 149 million USD annually in developing countries.[2] In Zimbabwe, over 25,000 households benefitted from the program related to seed relief between 2003-04 and 2006-07 crop seasons. The proportion of maize open pollinated varieties (OPVs) versus hybrids distributed in selected parts of Zimbabwe increased from 54 per cent when the programme was started in 2003-2004 to 95 per cent in 2006-2007. Recycling of OPV maize seed increased and significantly contributed to higher yields (Langyintuo and Setimela, 2007).

Benefits of rice breeding programmes were equally impressive. There was a gain of 0.94 tonne/ha in yield of rice in Asia, generating annual benefits of US$ 10.8 billion in South and South-East Asia. For Latin America, annual benefits were of about US$ 500 million (Table 2). Another significant advancement in rice research is development of new rices for Africa, which is a cross of Asian rice (*O. sativa*) having high productivity and African rice (*O. glaberrima*) having traits of wider adaptability. This new rice has an yield advantage of 24 per cent over local varieties (Dalton and Guei, 2003). The benefits of other rice breeding programmes in Africa were equally impressive—US$ 347 million (1998) and at least 29 per cent of these benefits could be attributed to CGIAR research.

Barley and sorghum are the crops of marginal production environments. Farmers growing these crops have benefitted immensely from breeding programmes of ICARDA and ICRISAT. It is found that benefits realized from barley program were US$ 92 million annually (1997) with IRR 32 per cent (Table 2). ICRISAT's sorghum varieties developed with Indian NARS were released and popular in Cameroon, Chad, Burkina Faso and Nigeria. And, sorghum varieties developed in Uganda were grown by farmers in Ethiopia, Kenya and Tanzania. The estimated IRR was 95 per cent for Chad, 75 per cent for Cameroon, 69 per cent for Mali and 22 per cent for Zimbabwe (*see* Annexure). These examples indicate that spill-over effects of widely-adaptable sorghum varieties were because of higher productivity and profitability.

Beans, cassava and potatoes are other important crops where development and adoption of improved varieties have been quite significant. Spread of beans varieties developed with substantial contribution from CIAT has been more in Latin America and Africa, and the estimated value of increased production was US$ 177 million and US $ 26 million per year, respectively (Table 2). Similarly, net present value of the investment in genetically improved dual-purpose cowpea research and extension in West Africa over 20 years was in the range of US$ 299 million to US$ 1,085 million. IRR

[2] Gollin, D. (2007). *Impacts on International Research on Intertemporal Yield Stability in Wheat and Maize: An Economic Assessment*. Department of Economics, Williams College, Massachusetts

Table 2. Summary of important crop research impact assessment studies

Study	Technology	Region	Study period	Type of analysis	Benefits
Lantican, Dubin and Morris (2005)	Wheat breeding research	Global	1988-2002	Value of additional wheat production	• Annual benefits US$ 2-6.1 billion (2002 dollars) • Benefits attributable to CIMMYT US$ 0.5-1.5 billion annually with a B-C ratio of 50 (most conservative estimate)
Hossain, Gollin, Cabanilla, Cabrera, Johnson, Khush and McLaren (2003)	Rice breeding research	Asia and Latin America	1965-1999	Net yield gains based on field-level data	• Yield gain of 0.94 t/ha (or US$ 150/ha) with annual gains of US$ 10.8 billion in South Asia and South-East Asia • Annual benefits US$ 500 million for Latin America • Significant increase in rice yield per day and tolerance to biotic stress
Zeddies, Schaab, Neuensch-wander and Herren (2001)	Biological control of cassava mealybug	Africa	1974-2013	Value of crop loss reduction, or saving of alternative crop i.e. maize	• Cassava loss reduction of US$ 26/ha with a total yearly gain of US$ 235 million (1994); B-C ratio of 199 • B-C ratio 170 with an yearly saving of US$ 200 million (1994) worth of maize • Benefits are much higher if the losses are compensated through cassava or maize imports
Morris, Mekuria and Gerpacio (2003)	Maize breeding research	Global	Late 1990s	Value of additional production	• Annual gains due to germplasm improvement US$ 668 million to US $ 2.0 billion • Annual benefits due to CIMMYT germplasm in the range of US$ 557 million to US $ 770 million
Aw-Hassan and Shideed (2003)	Barley germplasm improvement	Global	1980-2000	Economic surplus	• Annual gross research benefits US$ 92 million in 1997 • IRR 32 per cent

was between 50 to 103 per cent and benefit-cost ratio was between 32 and 127 using different assumptions (ILRI, 2007). Improved chickpea varieties from ICRISAT and ICARDA have also shown high adoption rates and returns in Turkey and non-traditional parts of Indian semi-arid tropics (Shiyani *et al*., 2002). It was also noted that ICARDA's lentil varieties were adopted widely in Egypt, Ethiopia, Pakistan and Central Asia.[3]

Improved varieties of cassava have been adopted on substantial area in Latin America, Africa and Asia and significant impact in Thailand was made by CIAT-related varieties. On average, cassava yield increased by 68 per cent on farmers' fields in Thailand and 80 per cent in Vietnam. The gross annual research benefits estimated were US$ 2.12 million (2003) with IRR 34-41 per cent, which may increase to 49.2 per cent if projected benefits for another five years were considered. Most of these benefits were realized through participatory research with improvement in knowledge of stakeholders and institutional learning. Similarly, CIP's potatoes breeding programme has made significant contributions, and it was estimated that IRR was 15 per cent (*see* Annexure).

Potential social welfare impacts of genetically modified (GM) bananas in Uganda revealed that delaying approval of GM banana can result into potential annual loss ranging approximately from US$ 179 million to US$ 365 million (Kikulwe *et al*., 2007). It is however,

[3] Anonymous (2007) http://www.icarda.org/Project4.2.htm

pointed out that realization of these benefits depends on consumers' perceptions and attitudes and willingness to pay for the GM technology.

In the fisheries sector, available studies reveal high positive contribution of improved practices. For example, Integrated Aquaculture Agriculture (IAA) in Malawi showed higher (11%) total factor productivity growth of adopters compared to non-adopters. Total income of adopter fishermen was 61 per cent more than non-adopters with an IRR of 12.2 per cent. Similarly, genetically improved Tilapia in Bangladesh, China, Philippines, Thailand and Vietnam showed yield gains ranging from 25 per cent to 78 per cent, and a high IRR (70%). Technological interventions of ILRI have been in terms of improving availability of fodder and livestock management, including animal health, and milk quality issues. Benefits of this research are discussed subsequently under the section natural resource management (*see* Annexure).

Above discussed studies confirmed scattered but successful spread of technologies based on genetic improvement programmes of CGIAR and nature and degree of their impacts (in some cases likely impact) for major food commodities. There have been appreciable technological advancements and impacts in pulses, millets and other food crops, but big stories still relate to wheat, rice and maize. The studies do, however, suggest that returns were higher than other alternative investment opportunities.

A noteworthy impact for non-genetic improvement, crop management research has been in the area of biological control of pest, especially cassava crop. This success led to system-wide programme on IPM which is coordinated by IITA. This is essentially a farmers' participatory programme with focus on research, technology dissemination and capacity building. Their target crops are cereals, pulses, potatoes and fruits. Yield gains were moderate (maize 20% in Kenya) to high (60% for faba bean in Egypt), besides health, environmental and social impacts. Another successful example of biological pest control has been of mango mealybug in Benin and estimated annual benefits in terms of additional mango production were US$ 50 million. Present value of accrued benefits was estimated at US$ 531 million over a period of 20 years, giving a benefit-cost ratio of 145 (Bokonon-Ganta 2001). Having tremendous success in cassava, mango and some other crops, IPM is being expanded to a variety of pests in different crops. The technology is information-intensive and being promoted through Farmer Field Schools (FFS). A number of studies have measured immediate impact of training and reported substantial and consistent reductions in pesticide use attributable to training. There was also a convincing increase in crop yield in few cases. However, the benefits were higher for vegetables and cotton than in rice (Van den Berg, 2004). Despite these impressive benefits realised on farms for several crops, spread of IPM technology has been rather limited. Some researchers while recognizing on-farm impacts of IPM have suggested to relook design and implementation of FFS and other technology transfer options for IPM (Waibel, 1999; Tripp *et al.*, 2006). Current focus of IITA programme on IPM is to address this constraint, as well as to meet pest management challenges arising from climate change, food safety and increasing eco-system resilience.

Natural Resource Management Research

Focus of agricultural research impact assessment has traditionally been on economic benefits realized through increase in crop productivity or cost savings. Benefits arising from research for natural resource management (NRM) and environmental protection have received rather less attention. Part of the problem could be attributed to methodological challenges associated with quantification of the benefits. It is only when a significant proportion of resources were spent on sustainability-enhancing programmes under extended research canvas of CGIAR that some efforts were made to assess their impacts (Waibel and Zilberman, 2007). These include technologies to promote sustainable use of natural resources. Results of the important studies assessing the technological impacts are summarized in this section.

NRM research covers a broad spectrum of issues on the management of land, soil, water and biodiversity. The research generates knowledge and technologies for increasing productivity and sustainability of ecosystems. The impact can be assessed at farm, community and landscape levels. However, such comprehensive studies are limited. SPIA of CGIAR initiated impact studies for some of the programmes started in the mid-1980s or early-1990s involving research cost of US$ 18 million. Impact studies covered soil conservation technologies, forest management, alley cropping, zero tillage, irrigation management transfer and integrated agriculture-aquaculture. Although full impact of these programmes is not yet realized, the results showed that most of these programmes have IRR of 12 to 48 per cent, This IRR is similar to other agricultural research but is not comparable with CGI research performance (CGIAR, 2006). This difference in the impact could be because of limited spread of NRM technologies owing to constraints associated with extension systems. Experience of zero-tillage is slightly different because this technology is targeted to the rice-wheat system of South Asia producing nearly half of total food grains. About two million ha area has been covered under zero-tillage, with a yield advantage of 5-10 per cent over the conventional tillage and cost reduction by US$ 65-180 for each ha.[4] Further analysis assuming an adoption level of 33 per cent indicates an IRR of 57 per cent. Both farmers and consumers shared the benefits (Vijaylaxmi *et al*., 2007). Higher benefits from zero-tillage technology and use of 'leaf colour charts' are testimony of partnership (especially of CIMMYT, IRRI, ICRISAT and IWMI) with NARS, private sector and NGOs. This calls for strong inter-centre partnersips to develop synergies and attain higher impact, especially of NRM technologies.

Besides above notable efforts, some more technologies for better management of cropping systems developed in partnership with NARS were subjected to impact assessments. Important among these are watershed management, site-specific integrated nutrient management, system of rice intensification (SRI) and low-external input or organic farming. The contribution of CGIAR to development of these technologies varies considerably and also difficult to assess with acceptable degree of reliability. Some of these technologies such as watershed management are being promoted for a fairly long period by national agencies, while others such as SRI and organic farming are comparatively new and they have already established their economic and environmental advantages on a large-scale.[5] In addition, adoption of these technologies suffers from the problems with technology transfer systems. Some of these technologies require collective action for realizing their impact in a particular area. Therefore, as stated earlier, partnership of more actors, especially with technology transfer system which is usually outside public research system, in an innovation system framework could be a possible option to accelerate the adoption process. Nevertheless, reported on-farm gains were substantial. Watershed programmes performed best when implemented in partnership with NGOs and backed with sound technical support. There were reductions in soil losses in upper watershed areas and water harvesting efforts increased availability of irrigation water. This raised crop yields and net returns under rainfed farming conditions (Kerr *et al*., 2002). Another important advantage of crop and resource management technologies and adoption of stress tolerance plant varieties was that yield risks have been reduced significantly (Gollin, 2006). This has direct benefits not only in stabilizing availability of food, but also reducing costs to hold buffer stocks.

Examples of such system-based interventions for optimization of use of farm resources for greater productivity and sustainability have been ICARDA's intervention of alley cropping in crop-livestock system in WANA. The intervention has not only improved availability of crop biomass, reduced feed cost for livestock and income from livestock during droughts, but also realized higher crop yields by reducting soil erosion (Shideed *et al*., 2007). Similarly, greater integration of acquaculture and agriculture in Malawi increased household income by 61 per cent and nutrition because of increase in fish consumption. Integration of suitable cultivars and crop management technologies has helped in reduction of striga in maize in Africa.

Environmental Impacts

Productivity-enhancing research helps conserve natural resources and environment. By saving natural resources that would have otherwise been required to produce more food and by increasing yields it reduces pressure to expand cropped areas. This helps save forest and other land from agricultural conversion which would otherwise have been brought under cultivation to meet food requirements (Nelson and Maredia, 1999). Credible empirical evidence of such impacts is fragmented. The broad estimates show that saving of land area in mostly developing countries is between 16 Mha and19 Mha. Obviously, this land would have been taken out from forests and fragile areas that are otherwise rich sources of agro-biodiversity. As a result,

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[4] The latest estimate is that zero tillage in various modifications is practised over three million ha in South Asia.

[5] For detail discussion, see Hazell, P. (2008). *An Assessment of the Impact of Agricultural Research in South Asia since the Green Revolution*. SPIA Study (draft).

area under forest did not shrink and remained almost constant in different parts of the world since the 1990s; in fact it improved in South Asia, the region having high population pressure.[6] These positive impacts, coupled with those of NRM research, have made impressive improvements in environmental sustainability, which are less quantified and documented. Some quantitative illustrations are:

(i) zero tillage technology reduced greenhouse gas emission and fossil fuel consumption; the technology saved 91 kg CO_2 emission per ha

(ii) improved tree-fallow system increased carbon sequestration (2.5-3.6 t/ha carbon stored)

(iii) Integrated aquaculture agriculture reduced nitrogen losses by 50 per cent and improved nitrogen-use efficiency

(iv) Introduction of alley cropping in crop-livestock system reduced soil erosion and increased organic matter in soil

(v) Adoption of IPM decreased pesticides use on farmers' fields and thereby reduction in soil, water and air pollution

Nevertheless, there is evidence in some reports that adverse consequences of intensification of production systems in both favourable and less-favourable areas neutralize some of the indirect benefits. In rainfed areas, problems are with land erosion, declining soil fertility and loss of biodiversity. These problems are more severe under conditions of high population pressure and incidence of poverty and limited options for diversification of rural livelihood. Intensification of irrigated production systems narrow down the genetic base, causing loss of natural (genetic) barriers to adverse production conditions, especially disease and insect outbreaks. Contamination of water with nitrates and phosphates from chemical fertilizers, unsustainable extraction of groundwater for irrigation, pesticide contamination and residue in food chain, salinity problems associated with irrigation and so on are other notable problems of intensification (Pingali and Rosegrant, 2001). More recent negative externalities such as herbicide resistance, pest resurgence and resistance, soil toxicity and water and air pollutions are further increasing environmental costs of the intensification process. Quantification of these costs is difficult but the concept of 'land savings' foregone, i.e., how much land would have been saved because of higher productivity had these problems not been there, is applied to assess the impact and it is estimated that land lost because of degradation (other than for salinity) is about 70-80 million ha globally (Maredia and Pingali, 2001). Not all of these losses could be attributed to the activities related to use of CGIAR research, and these are much lower than the estimated benefits in terms of land savings of 100-250 million ha due to productivity-enhancing research of CGIAR (Nelson and Maredia, 1999).

[6] FAO database on Global Forest Resources Assessment.

Income Distribution and Poverty

Distribution of the benefits of technological change can make significant impact on income inequalities; it can bring social change through poverty reduction and human resource development and can also strengthen economic and social institutions. The extent of such impacts, however, depends on the nature of technological change, extent of farm and non-farm linkages, markets and other support systems, and so on. The green revolution-type of technological change or persistence technological advancements have shown to reduce income inequalities and poverty. This impact is more pronounced in the production region where farmers adopting technology benefit from higher productivity and income. However, literature on distribution of these benefits among large and small farmers is diverse. Some studies showed that smallholders and other rural poor have also benefitted from technology adoption and occasionally they have gained proportional more than large farmers, reducing income inequality (Freebairn, 1995). At the same time, there are also examples that smallholders lag in technology adoption if it is influenced by resource base of farmers, or if smallholders attach high value to non-conventional criteria like risk and cost reduction over yield gain which is preferred by large farmers (Bourdillon *et al*., 2007). Over time, as farmers learn more about these new technologies, develop risk-proofing mechanisms through better management practices and land lease market develops, economic gains of technological change are more widely distributed. However, these economic gains may or may not be adequate to raise rural poor above the poverty line.

Technological change also reduces poverty through fewer direct ways. Agricultural growth can create

Table 3. Productivity and poverty effects of government investments in rural India: 1993

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

Source: Fan *et al*. (2000) but with additional calculations from Fan of the benefit/cost ratios. Cited from Hazell (2008)

employment opportunities for migrant workers and stimulate growth in non-farm economy to benefit rural poor (Chadha, 2007). Unfortunately, we could not locate any study which was based on post-2001 research outputs assessing research impact on income distribution and poverty. But there were econometrically sound empirical studies prior to 2001 which showed significant impact of research investment on poverty alleviation. It was concluded that one per cent increase in crop productivity reduces the number of poor people by 0.24 to 0.48 per cent in Asia and this reduction could be as high as 1.9 per cent in the long-run mainly through lower food prices and higher wages (Thirtle *et al*., 2003; Fan *et al*., 2000). Much of the agricultural growth can be attributed to agricultural R&D, making it a major source of poverty reduction (Table 3). Other studies also showed similar trends. For example, rice research in India and China in 1999 helped 3 million and 1.5 million people, respectively, escape poverty. A significant proportion of this impact could be attributed to rice research conducted in IRRI. It is estimated that for each million US dollars spent on rice research in IRRI, 15,490 poor people in India and 839 people in China in 1999 crossed the poverty line (Table 4). Similar trends are observed for impact of rice research on urban poverty.

However, these impressive impacts on poverty reduction are also associated with some not so appealing facts. There is a significant decline in the number of people lifted out of poverty because of research over time. For example, in China, reduction in the number of rural poor people because of rice research decreased from 23 million in 1981 to 5.2 million in 1991. This dropped to 1.53 million in 1999. The decline is even sharper for the number of rural poor for each million dollars of expenditure for IRRI (Table 4). This trend could be because of decline in importance of agriculture as a source of livelihood for rural poor who increasingly depend on non-farm activities for an alternate source

Table 4. Impact of rice research on rural poverty in India and China: 1991-1999

Year	India				China			
	Rural poor (million)	Reduction in number of poor from rice research (million)	Reduction in number of poor from IRRI research (million)	Reduction in number of poor people per million US$ of IRRI spending	Rural poor (million)	Reduction in number of poor from rice research (million)	Reduction in number of poor from IRRI research (million)	Reduction in number of poor people per million US$ of IRRI spending
1991	233	4.95	2.73	59,040	95	5.20	0.32	6,828
1992	237	5.12	2.89	59,379	90	5.89	0.30	6,224
1993	242	4.90	1.80	35,372	80	4.40	0.20	3,978
1994	274	5.29	1.95	43,629	70	3.57	0.15	3,362
1995	252	4.81	1.07	24,203	65	2.85	0.10	2,345
1996	251	4.39	0.99	23,033	58	2.98	0.09	2,022
1997	249	4.81	1.01	27,590	50	2.77	0.07	1,828
1998	212	4.23	1.02	28,221	42	2.15	0.05	1,254
1999	169	3.06	0.56	15,490	34	1.53	0.03	839

Source: Fan (2007)

of income. This speaks for increasing cost of poverty reduction through investment in agricultural R&D and therefore a relook at poverty focus of R&D programmes is needed.

Conclusions

The evidence summarized in this paper has clearly shown that agricultural research in general, and that done in CGIAR, has made a significant impact on agricultural growth, poverty reduction and environmental protection. However, there has been much variation in the impact of different Centres and research programmes. Most of the benefits have accrued to CGI research done by some of the founding Centres. The success of CGI programmes stems from free exchange of plant genetic resources and partnerships with NARS. Impact of natural resource and production system management research has been site-specific. Its spread has been restricted because of constraints on transfer of technology.

The evidence on research impact in SSA and WANA is limited comparatively to other parts of the world. This is because of a mix of technological, institutional and policy constraints. The same holds true to some extent for less-favourable areas of Asia—the region otherwise experiencing impressive impacts of research. Despite these limitations, empirical evidence clearly shows high rate of return to research expenditure made by CGIAR, thus justifying a higher level of funding. The rates of returns will be higher if they are adjusted to include the environmental benefits of research.

While the CG Centres prepare to address emerging challenges, they should strike a balance between strategic research aimed to produce international and regional public goods and impact-oriented location-specific action research when unrestricted funding is shrinking. The second major issue would be evolving a regionally differentiated strategy to address the challenges of subsistence, transforming and commercializing agriculture in developing countries, and having diverse technological needs and pathways for delivery and uptake of technologies. In particular, challenges to improve agricultural productivity in SSA will require not only developing technological solutions suited to smallholders but also inventing newer institutional arrangements to increase their spread. This may entail rethinking the issue of partnership among CG Centres, with NARS, CSOs and private organizations.

Poverty reduction has been an overriding objective of CGIAR. The available studies convincingly show a high degree of success in this area. However, there are indications that this impact is slowing down and cost of poverty reduction through research is increasing because of the changing importance of agriculture, particularly in transforming economies. The system needs to revisit this objective and draw appropriate suitable strategy for South Asia – having nearly half of the world's poor people, besides its continuing emphasis on programmes for SSA.

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Annexure

Summary of other CGIAR Impact Assessment Studies

Study	Region/ Country	Period	Level of Assessment	Impact
Place, Adato, Herbink and Omosa (2007)	Kenya	1997-2000	Rural poor in Western Kenya	• Doubling of maize productivity compared to no soil fertility replenishment (SFR); significantly better economic returns than with no SFR • The differences between improvement fallow and natural fallow systems are even more pronounced (94 % higher) • The per hectare net present value for the three year system using Crotalaria was US$ 351 compared to US$ 242 for the no-input control.
Fan (2007)	China and India	1992-1998	Country-level study on economic and social impacts	• Using US$ 1.5 poverty line, each additional 10,000 yuan increase in the 1998 stock of agricultural research raised 3.96 urban poor people above the poverty line in China. • For India, 72 urban poor were raised above the poverty line by per million rupees of research investment in 1995. • Total number of urban poor reduced by 2.96 million in China (1998) and 1.7 million in India in 1995.
Dalton, Lilja, Johnson and Howeler (2007)	Vietnam and Thailand	1994-2003	Farming system research, cassava	• Gross annual research benefits 2.12 million in 2003. • IRR 34-41 per cent which may increase to 49.2 per cent if projected benefits for another five years were considered • Contibution to knowledge improvement and institutional learning
Ajayi, Place, Kwesiga and Mafongoya (2007)	Zambia	1986-2002	Tree fallows in maize	• Yield gain 0.85 to 1.7 quintal/ha • Total benefits US$ 2 million during 2001-05 and could be US $ 20 million by 2010 • IRR – 15 per cent (over a 25-year period) • Carbon sequestration, risk reduction and reduced soil erosion
Maredia and Pingali (2001)	Global	1978-2000	Critical review	• Environmental impacts associated with soil degradation: Irrigation-induced soil salinity; soil degradation due to loss of nutrients, pollution and acidification is 163 million ha globally • Adverse impact on human health from use of chemical inputs. • Environmental impacts associated with the loss of genetic diversity on crop productivity and yield stability are difficult to assess
Pingali (2001)	Global	1970-1999	Annotated bibliography	• High returns to the CGIAR strategy of germplasm improvement • Savings in production costs due to technical change in crop management and increased input-use efficiencies • IPM: Benefit-cost ratio is 149:1 • Environmental, ecological, and human health impacts of modern technology have received limited attention from the CGIAR Centres
Nelson and Maredia (1999)	Country level	1970s to 1990s	Agriculture, forestry and fisheries	• Favourable impact on the environment from adoption of agricultural research results has been impressive • The environmental benefits associated with land saving from productivity research in seven key mandated food crops to be in the range of 170 to 460 million ha.

Contd.

Annexure— *Contd.*

Study	Region/ Country	Period	Level of Assessment	Impact
Walker, Bi, Li, Guar and Grande (2003)	Global	1993/94 -1998/99	Region level	• The adoption of CIP-related potato material in developing countries has been modest compared to the IARC performance in wheat, rice and maize. • Rate of return on investment about 15 per cent in CIP's potato breeding • 25 per cent of potato growing area under CIP-related materials in developing countries by 2020 would be an impressive performance
Dev and Bantilan (2003)	Global	1971-1998	Country level	• NPV of benefits from sorghum variety are estimated at US $ 15 million in Chad and US $ 4.6 million in Cameroon, with in IRR of 95 per cent in Chad and 75 per cent in Cameroon • Mali: NPV – US$ 16 million and IRR- 69 per cent • IRR from sorghum in Zambia and Zimbabwe are 11-15 per cent and 22 per cent, respectively
Shideed, Alary, Laamari, Nefzaoui and Morid (2007)	Morocco and Tunisia	1999-2003	Farm level of livestock systems indry areas	• The adoption rate was 30.6 per cent in 2002. • On average, reduction in feeding costs is estimated at 33 per cent • Results clearly support the effectiveness and economic feasibility of research investments in *Atriplex* technology; FIRR 50 per cent and EIRR 25 per cent
Aw-Hassan, Shideed with Sarker, Tutwiler and Erskine (2003)	Global	1980-1999	An economic surplus approach	• The total gross annual research benefits from lentil improvement for 1997 was estimated at about US $ 7.7 million for seven countries (Bangladesh, China, Egypt, Iraq, Pakistan, Jordan and Syria) • Large producing countries such as Bangladesh, China and Pakistan benefitted most from this technology.
Raitzer (2008, draft)	Indonesia	2000-2005 & 2007	Case studies on pulp and paper sector	• Shifts towards plantation based fiber supplies • Averted loss between 76,000 and 2,12,000 hectares of natural forest • Suggest counterfactual scenarios of slower adoption of improvements in the absence of CIFOR research
Kelley, Ryan and Gregersen (2008)	Global	1995-2006	CGIAR centre level	• Review of ex post economic impact assessment activity in the CGIAR • Desirable direction for impact assessment in the CGIAR, including broadening the work in terms of the types of research assessed and types of impact indicators used.
Raitzer and Winkel (2005)	Global	2003-04	Survey of CGIAR member agencies	• Majority of respondents (61%) opined research output is making significant contributions to the development goals • Moderate level of satisfaction of responsdents with epIA practices to-date in CGIAR. • Equal preference for large-scale estimates and household-level research impact. • Greater focus on poverty-related metrics and distribution of benefits was demanded by a large proportion of respondents.