CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

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International Agricultural Research for Food Security, Poverty Reduction, and the Environment

What to Expect from Scaling Up CGIAR Investments and "Best Bet" Programs

Joachim von Braun, Shenggen Fan, Ruth Meinzen-Dick, Mark W. Rosegrant, and Alejandro Nin Pratt

International Agricultural Research

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

The CGIAR, established in 1971, is a strategic partnership of countries, international and regional organizations, and private foundations supporting the work of 15 international agricultural research centers. In collaboration with national agricultural research systems, civil society, and the private sector, the CGIAR fosters sustainable agricultural growth through high-quality science aimed at benefiting the poor through stronger food security, better human nutrition and health, higher incomes, and improved management of natural resources.

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The International Food Policy Research Institute (IFPRI) was established in 1975. IFPRI is one of 15 agricultural research centers that receive their principal funding from governments, private foundations, and international and regional organizations, most of which are members of the Consultative Group on International Agricultural Research.

Legend for cover graphic—A Global CGIAR

- ▲ CGIAR Members
- CGIAR-Supported Centers
- ● CGIAR Regional Offices

Placement markers are approximate and indicate city locations.

Design by Joan Stephens, JKS Design

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Note: This paper is a work in progress and will be followed in 2008–09 with a more comprehensive strategic study of CGIAR center investment opportunities in cooperation with national agricultural research systems and the CGIAR Science Council.

Executive Summary

The recent food crisis, combined with the energy crisis and emerging climate-change issues, threatens the livelihoods of millions of poor people as well as the economic, ecological, and political situation in many developing countries. Progress in achieving development goals (such as cutting hunger and poverty in half by 2015) has been delayed significantly; in fact, the number of food-deficient people actually increased in the past two years by at least 75 million. These challenges require multifaceted, science-based technological, economic, and political approaches.

Through its international research centers, its publicly available research, its broad network of partnerships, and its long experience in the field, the CGIAR is well positioned to contribute to the global effort to foster food production, increase access to food, and reduce poverty and hunger in both rural and urban areas. However, the system cannot effectively address these global challenges without additional funding and improved organizational design. The latter is being addressed by an ongoing change process. The former is the focus of this paper, which examines what can be expected from a scaled-up CGIAR.

There can be no doubt about the strong role of agricultural research in concert with other development investments: numerous studies have shown that investments in agricultural research typically rank first or second in terms of returns to growth and poverty reduction, along with investments in infrastructure and education. Fortunately, there is a new and broad-based consensus that investment in agriculture and in related, research-based innovations must be accelerated. But the obvious questions are, by how much should this investment be accelerated, where should it be focused, and what can be expected from it?

This paper utilizes two different approaches to assess the impact of significantly scaling up investment in public agricultural research in developing countries in general, and in the CGIAR in particular. First, it models the potential impact of doubling research investment on agricultural (food) production and poverty reduction, and also on international food prices. It then provides a compilation of "best bets" for large-scale research investments, as identified by the CGIAR centers in a survey done for this study.

The modeling indicates that increasing investment in public agricultural research in the countries included in the model from about US$4.6 billion to US$9.3 billion during the next five years (2008–13), and doubling CGIAR investment from US$0.5 to US$1.0 billion as part of that, would increase output growth coming from research and development (R&D) from

0.53 to 1.55 percentage points. Doubling this R&D investment would also reduce $1-a-day poverty by 204 million people by 2020. This scenario assumes that expanded investment is targeted toward maximizing total agricultural output, which means allocating R&D investment more to Southeast/East Asia and South Asia than other regions. If, on the other hand, expanded agricultural research is targeted toward maximizing poverty reduction, then R&D investment should be allocated more to Sub-Saharan Africa and South Asia. This would increase overall agricultural output growth somewhat less (from 0.53 to 1.11 percentage points per year), but would lift about 282 million people out of poverty by 2020 (compared with 204 million in the first scenario).

A different global model (IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade [IMPACT]) was used to estimate the effects of accelerated R&D investment—combined with plausible increases in other development investments—on international food prices. The results suggest that when compared with the baseline scenario, a high-investment scenario could reduce the price of maize by 67 percent in 2025, wheat by 56 percent, and rice by 45 percent, while reducing unit costs of production to main farm income. Such expanded R&D investment in agriculture is critical for preventing future global food crises.

The paper also describes 14 examples of "best bets" for large-scale research investments, ranging between about US$10 million and US$150 million each over five years.[1] They encompass the broad areas of increasing the agricultural productivity of crop and livestock systems, reducing risks, improving the nutritional quality of food, mitigating climate change and improving ecosystem resilience, enhancing germplasm exchange, and improving market information and value chains. These illustrative "best bets" include

1. revitalizing yield growth in intensive cereal systems [estimated investment: US$150 million; people reached: 3 billion];
2. increasing fish production [estimated investment: US$73.5 million; people reached: 32 million];
3. addressing threatening pests such as virulent wheat rust [estimated investment: US$37.5 million; people reached: 2.88 billion];
4. tackling cattle diseases such as East Coast Fever [estimated investment: US$10.5 million; people reached: 20 million, with additional indirect effects on many more];

5. breeding drought-resistance maize in 20 countries [estimated investment: US$100 million; people reached: 320 million, with additional indirect effects on many more];
6. scaling up biofortification [estimated investment: US$125 million; people reached: up to 672 million];
7. including poor forest people in opportunities for climate change mitigation [estimated investment: US$45 million; people reached: 48 million];
8. enhancing yield growth in the context of climate change [estimated investment: US$127.5 million; people reached: 1.18 billion];
9. combining organic and inorganic nutrients for increased crop productivity [estimated investment: US$55 million; people reached: 400 million];
10. promoting the sustainable and efficient use of groundwater [estimated investment: US$24 million; people reached: 261 million];
11. expanding the exchange of genetic resources [estimated investment: US$15 million; people reached: global impact, with a focus on developing countries];
12. promoting innovations to improve small farmer access to trade, market, and value-chain systems in six countries [estimated investment: US$10.5 million; people reached: 45 million];
13. ensuring women's full participation in agricultural innovation [estimated investment: US$30 million; people reached: 200 million]; and
14. reducing the adverse effects of agriculture on health and improving the health benefits of agriculture for the poor [estimated investment: US$75 million; people reached: global] .

These "best bets" would reach billions of people, even before assessing synergies and adding up effects across "best-bet" programs. While some of these "best bets" are currently on the desired and actual agenda of the CGIAR, the respective investments are currently far below the needed scale for optimal impact. The CGIAR is also constrained from effectively utilizing new science in biotechnology and nanotechnology for the poor, which should be included among the emerging opportunities that require scaling up of investment in the CGIAR. While most of the identified CGIAR research opportunities are characterized by large-but-slow wins, some have opportunities for large-scale, quick wins, especially institutional and policy research that leads to policy changes in the short run, such as research related to markets and to food and nutrition programs and policies.

A reformed and more efficient CGIAR will not only help increase productivity, improve the natural-resource base, and strengthen policy and institutions through its own research, but will also be better able to link with private-sector innovation and end-user oriented operations in cooperation with national agricultural research systems (NARS), which would yield high pay-offs to development investments.

The Challenge

Slow increases in world food production and declining rates of yield growth in main food crops threaten world food security. Land and water constraints, underinvestment in rural infrastructure and agricultural innovation, lack of access to agricultural inputs, and weather disruptions are impairing productivity growth and the needed production response. These factors, combined with sharp increases in food prices in recent years, have added to concerns about the food and nutrition situation of people around the world, especially the poor in developing countries. Nearly every agricultural commodity—including dairy products, meat, poultry, oil seeds, and cassava—has been part of the rising price trend. Several factors have contributed to these unprecedented food price increases: climate change, rising energy prices and subsidized biofuel production, income and population growth, globalization, and urbanization. But it is the long-run stagnation and/or decline in public research in many poor countries and within the Consultative Group on International Agricultural Research (CGIAR) itself that has been a major force behind the slow increase in the global supply of food.

Meeting the complex challenge of reducing poverty and ending hunger and malnutrition in a sustainable manner in light of these needs requires multifaceted economic, political, and technological approaches. Because technological innovation is especially important when resources are scarce, world leaders and the international community are calling for renewed and significantly increased support to agricultural science and technology to help achieve global food security in the medium to long term.

Through its 15 international research centers, its publicly available research, and its broad network of partnerships with national agricultural research systems (NARS) and numerous other organizations and institutions, the CGIAR is well positioned to contribute to this global effort to reduce hunger. It seeks to achieve its vision of "a world free of poverty and hunger, supported by healthy and resilient ecosystems" by undertaking research in three strategic areas:

1. Food for People: create and accelerate sustainable increases in productivity and the production of healthy food by and for the poor;
2. Environment for People: conserve, enhance, and sustainably use natural resources and biodiversity to improve the livelihoods of the poor, and respond to climate change; and

3. Innovation for People: mobilize science and technology to stimulate institutional innovation and enabling policies for pro-poor agricultural growth and gender equity.

After nearly two decades of neglect, the role of agriculture and agricultural research in addressing climate change, high food prices, environmental and energy crises, and other issues of global importance is receiving high-level political recognition.

After nearly two decades of neglect, the role of agriculture and agricultural research in addressing climate change, high food prices, environmental and energy crises, and other issues of global importance is receiving high-level political recognition. The *World Development Report*, policy statements from the European Union, and numerous recent reports from other institutions are again focusing attention on the agricultural innovation system. World Bank President Robert Zoellick recently challenged supporters to double investment in the CGIAR, a sentiment that has since been echoed by a number of other major actors in the development arena. In a July 2008 statement, the Group of Eight (G8) leaders also supported the promotion of agricultural research and development through the CGIAR. The obvious questions are: where should expanded investment be focused and what can be expected from it?

This paper uses two approaches to highlight the potential growth and poverty-reduction impacts, as well as the effects on food prices, of expanded funding to the CGIAR: first, it presents modeling of the effects of agricultural research investment globally and by region, and second, it provides an assessment of illustrative "best bets" for large-scale research investments serving the three strategic objectives of the CGIAR.

The Need for Agricultural Innovation and the Role of the CGIAR

Challenges and Opportunities

The livelihoods of many smallholders and rural people depend directly on their ability to produce and market agricultural products. Therefore, agricultural growth in developing regions remains fundamental for poverty reduction and food security. Without urgent revitalization of the sector, however, the first Millennium Development Goal (MDG) to halve poverty and hunger by 2015 will not be reached. If poverty and hunger are to be eradicated in the longer term, substantial investments must be made in agricultural research and innovation.

Improved agricultural systems also have crucial roles to play with regard to other development goals, including the MDGs related to achieving greater environmental sustainability, improving access to water, promoting gender equality, reducing child mortality, and improving maternal health. Agricultural research must tackle how best to manage the scarce resources that contribute to agricultural production, including water, soils, forests, and fisheries. Because climate change increases uncertainty about climatic events and raises poor farmers' vulnerability to crop losses and damage, research is essential to identify means of adapting agricultural systems to changing environmental conditions and determine how to better manage agricultural and forest systems to mitigate climate change.

Agriculture also has the potential to significantly impact health—negatively through the prevalence of food-borne contaminants such as aflatoxins, for example, and positively through the potential for improved nutrition, such as through biofortification and making healthy diets affordable for the poor. Agricultural systems themselves severely impact the health of rural people through pesticide misuse and the creation of breeding habitats for disease vectors, for example. Therefore, agriculture's close connection to health demands research attention to pursue future improvements in health and nutrition.

At all levels, these and other crucial development challenges cannot be addressed without a specific focus on empowering women to grasp opportunities for improving their livelihoods and those of their families.

Finally, agricultural research is not only essential for meeting the challenges involved in reducing hunger and poverty, but also crucial for taking advantage of innovative opportunities for developing-country food systems via cutting-edge science—including information technology, biotechnology, and nanotechnology. For example, nano-technology may improve agricultural productivity in the future by decreasing crop and postharvest losses and improving the efficiency of productive inputs. Nanotechnology applications may also create opportunities for new, value-added, commodity-based products such as functional foods and biofuels.

Agricultural research is not only essential for meeting the challenges involved in reducing hunger and poverty, but also crucial for taking advantage of innovative opportunities for developing-country food systems via cutting-edge science—including information technology, biotechnology, and nanotechnology.

CGIAR: Innovating for Impact

As a major contributor to agricultural innovation in partnership with NARS, the CGIAR was born out of a need to extend the Green Revolution's agricultural, technological, and institutional advances. However, the CGIAR does not need to invoke its early successes to make a business case for an expansion of investment today. Since its many early achievements, it has continued to be at the forefront of agricultural innovation in developing countries (see Annex 1 for a list of some of the CGIAR's major research contributions). Significant recent accomplishments include its wheat- and rice-breeding activities, as well as its work on disease-resistant cassava.

International wheat-breeding research continues to have huge impacts on wheat production in the developing world. In 2002, 68 percent of the developing world's total wheat area was sown to varieties containing CIMMYT-related germplasm. CIMMYT wheat-breeding research has contributed to additional wheat production valued at US$0.5–1.5 billion annually (using a conservative 2002 estimate) and US$1.3–3.9 billion (using a more liberal estimate). Factoring the cost of CIMMYT's wheat-breeding research during 2002, the benefit–cost ratio lies between 50 and 390 to 1. The benefits of CIMMYT's wheat-breeding research are even higher when improved grain quality, improved straw quality and quantity, and shorter growing cycles are taken into account in addition to yield gains.[2]

In terms of the CGIAR's rice-breeding work, more than 330 IRRI breeding lines have been released as more than 650 varieties in 77 countries. It is estimated that 60 percent of the world's rice area is now planted to IRRI-bred varieties or their progenies. The development and adoption of semi-dwarf varieties has more than doubled global rice production from 256 million metric tons (mt) in 1965 to more than 630 million mt in 2007. Shifting from traditional to modern varieties increased farmers' yield by 2.1 mt per hectare, on average, and resulted in an annual benefit estimated at US$10.8 billion.[3] New Rice for Africa (NERICA) varieties, which were developed by WARDA in the 1990s, have also significantly raised yields, production, and the incomes of producers in Africa. The adoption of NERICA rice has increased average annual yields by 850 kilograms per hectare (kg/ha) for female farmers in Benin and by 741 kg/ha in Côte d'Ivoire. In Uganda, on average, farmers who shifted from maize to NERICA rice production saw an increase in incomes of US$273–481 per hectare, with proper crop rotation. The impact of NERICA technology has also led to higher school attendance, increased gender parity, increased household consumption spending, and higher calorie intake in Africa.[4]

World agricultural productivity, particularly in poor countries, is key to global food security and the fight against hunger and poverty. It will remain the top priority of CGIAR research. A contributing factor in CGIAR successes is research on natural resource management (NRM), policy, and gender. The long-term impact of this work is harder to quantify and put into cost-benefit analyses but is of equal significance:

- Achieving productivity increases often requires accompanying improvements in capacity to use the natural resource base (soil, water, biodiversity) that are linked to NRM or policy research, or to women's access to the benefits of agricultural research.
- Addressing the MDGs related to poverty reduction and gender requires addressing how productivity increases are translated into food security and environmental sustainability, which in turn requires looking at the distribution of benefits and underlying resource conditions.
- Climate change is creating a greater premium for mechanisms to reduce the extent of climate change or its adverse impacts on the poor. Finding such mechanisms requires looking at resource management practices and how they can sequester carbon or temper fluctuations in water availability or other conditions, or shield the poor or marginal groups from risks and the effects of fluctuations.

All innovation involves risk, and innovative research is no exception. It requires exploration and allowing for failures. It would be a bad sign if the CGIAR system did not have any unsuccessful projects, as that would indicate it was not taking risks or thinking boldly. However, review processes take note of such cases and sooner or later, dead-end explorations are stopped. Nonetheless, there are significant lessons to be learned from the less-

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successful initiatives as well as from the successful ones, and the CGIAR continuously takes stock of these experiences to evolve into a more efficient and effective organization.

As poor people in the developing world feel the pressure of climate change, high food prices, and environmental and energy crises, the need for new knowledge, technologies, and policy insights has become more critical.

Investing in the Future

As poor people in the developing world feel the pressure of climate change, high food prices, and environmental and energy crises, the need for new knowledge, technologies, and policy insights has become more critical. Global economic and population growth have contributed to increased pressure on food supplies. Natural resources are already overstressed, and further expansion of the agricultural frontier is not an option in most cases.

Given the global nature of these challenges and the opportunity to gain from economies of scale and scope, the CGIAR can and must play a central role in the agricultural innovation system. If its funding were doubled to US$1 billion per year, the CGIAR would be in a position to not only double its current poverty-reduction and hunger-alleviation efforts in a "more of the same" sense, but also to expand the multiplier effects of its activities, especially in relation to the NARS.[5]

The following section presents some modeling of the expected effects of increased agricultural research investment, globally and by region.

The Impact of Expanded Investment in Agricultural Research for Growth and Poverty Reduction

How much impact will expanded research investment generate in terms of production/productivity and poverty reduction? In this section, we will first review trends in agricultural research and development (R&D) spending by both NARS and the CGIAR (Figure 1), as well as trends in productivity. We then present a simple model to simulate the impact of doubling agricultural R&D investments in five years on agricultural production growth and poverty reduction. We deliberately do not attempt to separate the effects of CGIAR vs. NARS investments since these two forces are highly complementary to each other in close partnership; international and national agricultural research must expand in tandem.

Research Investment, Productivity, and Benefits

Public Agricultural R&D Spending

Total agricultural R&D spending in developing countries increased from US$3.7 billion (1991) to US$4.4 billion (2000), or by 1.6 percent annually.[6] This spending was largely driven by Asia, where annual spending increased by 3.3 percent. In Africa, agricultural R&D expenditure actually declined slightly, by 0.4 percent a year. Latin America's expenditure grew marginally, by 0.5 percent a year during this period.

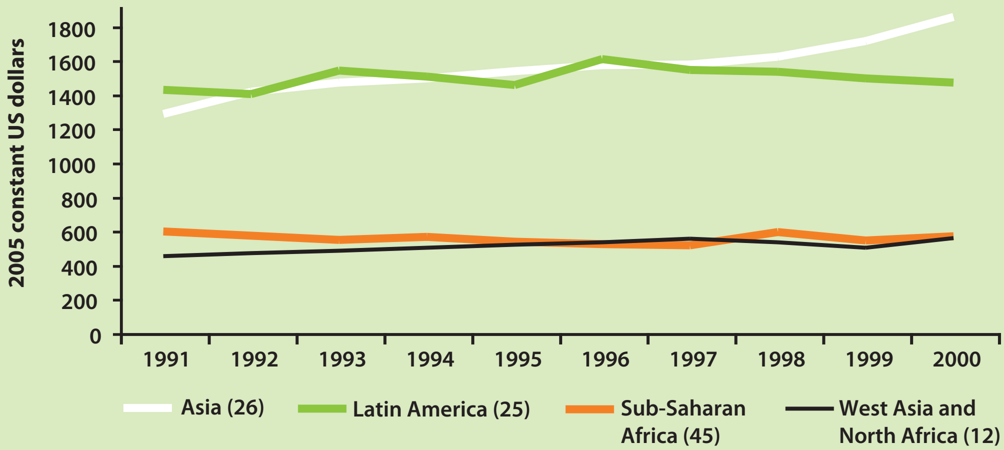
As a result, the regions of the world are sharply divided in terms of their capacity to use science to promote productivity growth to achieve food security and reduce poverty and hunger. Today, Asia accounts for 42 percent of total agricultural R&D spending in developing countries (with China and India accounting for 18 and 10 percent, respectively, of that share). Although Africa is geographically large, its share is only 13 percent. Latin America accounts for 33 percent (with Brazil being responsible for 48 percent of the region's spending). For every US$100 of agricultural output, developed countries spend US$2.16 on public agricultural R&D, whereas developing countries spend only US$0.55.[7] This highlights the underinvestment in agricultural R&D in developing countries and the gap between rich and poor nations in generating new technology.

CGIAR Spending

CGIAR funding increased only slightly from US$405.5 million in 1991 to US$445 million in 2006 (measured in 2005 U.S. dollars), representing an annual growth of 0.49 percent. In 2000, the CGIAR accounted for 8.6 percent of agricultural research spending in developing countries, declining from 11 percent in 1991.[8] CGIAR spending is relatively small in Asia, West

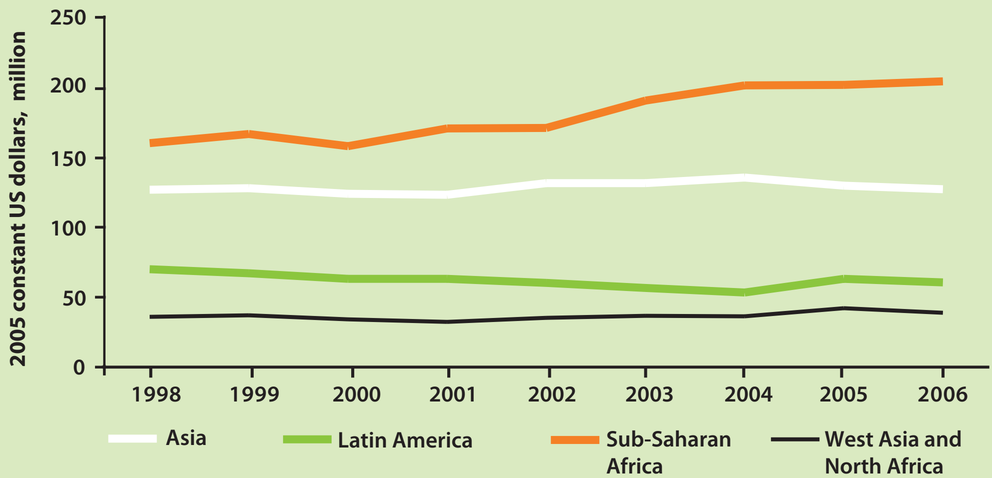
Figure 1—Trends in agricultural R&D spending.

1A. Agricultural R&D spending in developing countries (millions of 2005 US$)



Source: Authors' calculations from Agricultural Science & Technology Indicators (ASTI) datasets.
Note: The number of countries included in the regional totals is shown in parentheses.

1B. Expenditure by the CGIAR (millions of 2005 US$)



Source: CGIAR.

Asia and North Africa, and Latin America (accounting for 7 percent, 6 percent, and 4 percent, respectively, of their total national system investment), but is large in Africa (28 percent).

Productivity

Productivity has risen in many developing countries, mainly as a result of investment in agricultural R&D combined with improved human capital and rural infrastructure. In East Asia, land productivity increased from US$1,485/ha in 1992 to US$2,129/ha in 2006, while labor productivity rose from US$510 to US$822/worker (Table 1). In Africa, the levels of productivity are much lower, and their growth has also been slower. In 1992, land productivity in SSA was only 79 percent of that in East Asia (indicating a 21 percent gap); by 2006 the gap had increased to 59 percent. Growth in total factor productivity (TFP, derived from the ratio of total output growth to total input growth), exhibits even larger variation among regions. From 1992 to 2003, East Asia and Latin America experienced the most rapid growth at 2.7 percent per year. East Africa had the lowest growth. TFP in other regions grew between 1 and 1.6 percent.

Returns to Investment in NARS and IARC

Returns to agricultural research have proven to be very high. On average, the rate of return (ROR) to NARS in developing countries is 60 percent (see Table 2), which is higher than investments in education and roads.[9] The Asia and Pacific region has the highest ROR (78 percent), while Africa has the lowest, but even the African ROR is high (49.6 percent). The median ROR exhibits similar patterns among regions; Asia and Pacific has the highest while Africa has the lowest and Latin America falls between. The ROR for international agricultural research centers (IARC) is much higher than that for NARS. In Africa, the median IARC ROR is 83 percent higher than for NARS, while in Asia and Pacific the gap is 72

Table 1—Agricultural productivity in developing countries

	Land		Labor		TFP
	1992	2006	1992	2006	1992–2003
	(2005 constant US$/ha)		(2005 constant US$/worker)		(annual % growth)
East Asia	1,485	2,129	510	822	2.7
South Asia	813	1,156	539	644	1.0
East Africa	503	514	347	351	0.4
West Africa	408	521	601	730	1.6
Southern Africa	255	229	234	190	1.3
Latin America	1,129	1,614	3,294	5,402	2.7
NAWA	785	1,121	1,785	2,184	1.4
Average	**846**	**1,198**	**591**	**827**	**2.1**

Source: Authors' calculations based on FAOSTAT data.

Table 2—Rates of return of NARS and IARC

	Alston et al.	Evenson	Evenson and Gollin
	NARS Mean	NARS Median	IARC
Developing countries	60.1	…	…
Africa	49.6	37	68
Asia and Pacific	78.1	67	115
Latin America	53.2	47	39
IARC	77.8	…	…

Sources: J. Alston, C. Kang, M. Marra, P. Pardey, and T. Wyatt. 2000. *A meta-analysis of rates of return to agricultural R&D: Ex pede Herculem?* IFPRI Research Report 113. Washington, D.C.: International Food Policy Research Institute.

R. Evenson. 2001. Economic impacts of agricultural research and extension. In B.L. Gardner and G.C. Rausser (eds.), *Handbook of Agricultural Economics*, Vol. 1. Amsterdam: North-Holland.

R. Evenson and D. Gollin. Contributions of national agricultural research systems to crop productivity. In R. Evenson and P. Pingali (eds), *Handbook of Agricultural Economics*, Vol. 3. Amsterdam: North-Holland.

Note: IARC=International agricultural research centers.

percent. The gap in Latin America is only 21 percent. This pattern indicates underinvestment in international public goods–type agricultural research and also points to the need for increased investment in capacity strengthening within NARS.

Simulating the Impact of Doubling R&D Funding within Five Years

We use a simple approach to simulate the allocation of R&D research investment among regions.[10] The regions considered are Sub-Saharan Africa (comprising Southern, West, and East Africa, but not South Africa); West Asia and North Africa (WANA); South Asia; Southeast/East Asia; and Latin America and the Caribbean (LAC). In our simulation, NARS spending and CGIAR spending are combined as total spending that affects agricultural productivity in developing countries.[11]

We assume that the level of agricultural output in each region is the result of the use of inputs (land, labor, tractors, animal stock, and fertilizer), which we fix at their base observed level, and the stock of R&D. With inputs fixed, agricultural output is determined by R&D stock, which in turn is determined by the weighted average of the past seven years of R&D investment and the production elasticities of R&D stock.[12] Two scenarios are considered:

- The first scenario assumes that present total investment is doubled in five years and that incremental R&D investment is allocated to different regions each year via an optimization problem that ***maximizes total agricultural output***, subject to each region's agricultural output response to R&D and the level of R&D stock in each region. A move to increase CGIAR funding from the current $500 million to $1 billion would be part of this change.[13]

- The second scenario assumes that present total investment is doubled in five years and that incremental R&D investment is allocated to different regions each year via an optimization problem that ***minimizes poverty***, subject to each region's agricultural output response to R&D and the response of poverty to agricultural output growth in each region.

As in the case of output response to R&D, changes in poverty due to agricultural growth are also defined using poverty elasticities from the literature.[14] No price effects are considered in the optimization problem, and the model assumes no spillovers of R&D investment to other regions.[15]

Under the first scenario, ***maximizing total agricultural output***, output growth coming from R&D would triple (from 0.53 in 2008 to 1.55 percentage points in 2020), which would increase the overall output growth rate from 3.6 to 5.05 percent. Regionally, Southeast/East Asia's output growth coming from R&D would increase by 2.26 percentage points, South Asia's by 1.78 percentage points, and Africa's by 1.1 percentage points (Table 3). In order to maximize total agricultural output, R&D investment should therefore be allocated to Southeast/East Asia and South Asia.

Increased investment allocated to maximize agricultural output would reduce the total number of poor by 204 million between 2008 and 2020. Of these, almost 95 million live in South Asia (with 71 million in India), 67 million in Sub-Saharan Africa (53 million in West Africa), and 41 million in Southeast/East Asia.

Table 3—R&D investment and its impact on poverty and output growth under output maximization

	Allocation of R&D investment (million 2005 US$)		Change in the number of poor (millions)	Agricultural output growth rate (%)
Region/country	2008	2013	2008–2020	2008–2020
Sub-Saharan Africa	608	933	–67.2	1.14
East Africa	287	371	–11.9	0.77
Southern Africa	88	100	–2.5	0.37
West Africa	233	462	–52.9	1.44
West Asia & North Africa	546	614	–0.02	0.23
South Asia	908	2,131	–95.4	1.78
India	707	1,638	–71.3	1.76
Southeast/East Asia	1,956	5,268	–41.0	2.26
China	1,457	4,247	–29.4	2.37
Latin America	957	1,004	–0.2	0.08
Total	**4,975**	**9,951**	**–203.8**	**1.55**

Source: Authors' estimates using the optimization model.

Table 4—R&D investment and its impact on poverty and output growth under poverty minimization

Region/country	Allocation of R&D investment (million 2005 US$) 2008	2013	Change in the number of poor (millions) 2008–2020	Agricultural output growth rate (%) 2008–2020
Sub-Saharan Africa	608	2,913	–143.8	2.75
East Africa	287	803	–28.9	1.93
Southern Africa	88	308	–11.3	1.89
West Africa	233	1,803	–103.6	3.30
West Asia & North Africa	546	614	–0.02	0.23
South Asia	908	3,111	–124.6	2.40
India	707	2,358	–92.7	2.35
Southeast/East Asia	1,956	2,323	–13.5	0.69
China	1,457	1,730	–8.9	0.69
Latin America	957	990	–0.2	0.07
Total	**4,975**	**9,951**	**–282.1**	**1.11**

Source: Authors' estimates using the optimization model.

Notes:
- East Africa includes Burundi, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania, and Uganda.
- Southern Africa includes Angola, Botswana, Comoros, Lesotho, Malawi, Mozambique, Mauritius, Namibia, Swaziland, Zambia, and Zimbabwe.
- West Africa includes Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo Republic, Congo Democratic Republic, Côte d'Ivoire, Gabon, Gambia, Ghana, Guinea Bissau, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo.
- WANA includes Algeria, Egypt, Libya, Morocco, Tunisia, Iran, Jordan, Lebanon, Syria, and Turkey.
- South Asia includes Bangladesh, India, Nepal, Pakistan, and Sri Lanka.
- Southeast/East Asia includes China, Indonesia, Malaysia, Mongolia, Philippines, Thailand, and Vietnam.
- Latin America includes Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, El Salvador, Honduras, Guatemala, Panama, Paraguay, Peru, Nicaragua, Uruguay, and Venezuela.

The poverty rate in Southeast/East Asia would decrease from 11 to 9 percent from 2008 to 2020, while in South Asia it would decrease from 35 percent to 28 percent. In West Africa, the poverty rate would drop from 56 to 41 percent.

Under the second scenario, ***minimizing poverty***, more R&D investment should be allocated to Sub-Saharan Africa (SSA) and South Asia. Most of the poor earning less than $1 a day live in South Asia (500 million) and in SSA (300 million), which means that to effectively reduce poverty, a significant share of R&D investment should be allocated to those regions. Increased R&D investment would reduce the number of poor by 282 million from 2008 to 2020, which is about 200 million more than under a business-as-usual scenario (Table 4). Of the 282 million, 124 million would be in South Asia and 144 million would be in SSA (with 104 million in West Africa). The poverty rate in South Asia would decrease from 35 percent in 2008 to 26 percent by 2020, which is 2 percentage points below that in the first scenario. The poverty rate in Africa would decrease from 48 percent to 25 percent, since minimizing poverty requires that a large share of total R&D investment be directed to Africa.

Impacts of Expansion of R&D Investment on Long-Run Prices

According to recent estimates by the Food and Agriculture Organization of the United Nations (FAO), rising food prices have reversed progress toward meeting the MDG hunger target, with the proportion of hungry people in the developing world sliding back to 17 percent—about the same level as a decade ago.[16] In view of this situation, the role of agricultural R&D expansion is critical for the long-run food security of the poor, even beyond farm populations. This economywide effect of international agricultural research through prices is becoming even more important as the world becomes increasingly urbanized, and as the poor in both urban and rural areas increasingly rely on multiple income sources. IFPRI's IMPACT model was used to calculate the effects of accelerated R&D investment—combined with plausible increases in other development investments (rural roads and irrigation)—on international food prices, under a baseline (business-as-usual) scenario versus a very high investment scenario.[17] The results suggest that very high agricultural R&D investment combined with other investments could greatly reduce food prices compared to the baseline scenario. By 2025, aggregate cereal global trade prices could be nearly 60 percent lower than they would be in the baseline (-45 percent for rice, -56 percent for wheat, and -67 percent for maize).

When improved access to food through increased investment in agricultural R&D is combined with other key poverty-reducing investments (schooling, basic health services, and safe water sources), the number of malnourished children (by weight, ages 0–5) would also be dramatically reduced compared to the baseline. The very high investment scenario would lead to a 31 percent reduction in the number of malnourished children in 2025, compared to the baseline case in those same years (from 150 million to 100 million malnourished children in 2025).

"Best Bets" for Agricultural Research at Global and Regional Levels

This section examines some of the specific ways in which investment in international agricultural research could lead to sustainable poverty reduction. The types of investments are grouped according to the CGIAR's strategic objectives. These are illustrated with a set of "best bets" for CGIAR investments in coming decades, based on a survey of CGIAR and other scientists and research leaders. This is not a comprehensive list, but an indicative one that presents some key examples and their likely impact in terms of their developmental and environmental effects and their reach to the poor. A more complete listing of opportunities and investments can be found in Annex 2.

FOOD FOR PEOPLE: create and accelerate sustainable increases in productivity and production of healthy food by and for the poor

The need for increased agricultural productivity, not only to increase farmers' incomes but to ensure affordable food for growing urban populations, is one of the main tasks of the CGIAR and its partners. Achieving this is becoming more difficult in many areas where the land and water resource base is shrinking due to competition with urban uses or degradation of soils and water, and where climatic fluctuations and pests or diseases threaten the supply and stability of production. The CGIAR is uniquely placed to address these challenges because it can forge multi-disciplinary partnerships in developing countries that link cutting-edge science and an enormous pool of genetic resources to local needs via breeding, molecular biology, food science, human nutrition, farm extension, communication, marketing, and economics to achieve sustainable intensification. "Best bets" for CGIAR investments in this area are grouped around the themes of increasing the productivity of crop and livestock systems, reducing biotic and abiotic stress, and improving the nutritional quality of food. Most of the investments described contribute to more than one of these themes.

Increasing the Productivity of Crop and Livestock Systems

Major work is underway to increase the productivity of crop and livestock systems, including in the vulnerable drylands areas. Both conventional breeding and biotechnology provide tools to increase the yield potential of staple grains, roots, and tubers, which is important for the future of agriculture. Much of the improvement in crop yields, especially in Africa, relates to improved soil and natural resource management practices. There are also important opportunities for increasing the productivity of legumes and other staple and high-value crops, transforming livestock production through improved feeding systems to increase production with less land, and increasing protein and incomes for the poor through aquaculture and fisheries management. Integrated development and testing of biophysical, social, economic, and policy interventions to adapt small ruminant and feed resources management strategies while protecting the environment offer significant potential in dryland areas.

Revitalizing yield growth in the intensive cereal systems of Asia—Intensive cereal cropping systems in Asia provide economic activity and staple food for hundreds of millions of people. In the 1990s, however, yield growth stalled, setting the stage for the higher food prices. Closing the gap between current farmers' productivity and potential yields through agronomic practices such as improved seed handling, land leveling, water-saving technologies, reduced tillage, and postharvest processing can achieve much in the short term. Economically exploitable yield gaps of 1 to 2 mt/ha exist in most rainfed and irrigated lowland rice environments, and postharvest grain losses are often 10–20 percent. Efforts to increase the yield potential of rice and wheat need to be revitalized with hybrids and inbreds, and livestock production needs to be accelerated through improved use of residues. **[Total investment: US$150 million over 5 years. People reached: more than 3 billion].**

Ensuring productive and resilient small-scale fisheries—One billion people rely on fish as their primary protein source, and several hundred million people depend on fish as their main source of income. Small-scale fisheries (SSFs) provide two-thirds of the global fish catch and more than 95 percent of employment in fisheries. To sustain SSFs and enhance their benefits, threats to fisheries (including from water management, climate change, and overexploitation) need to be identified and addressed. Improved governance and effective benefit sharing through community-based fishery management and equitable contracts, especially through trade associations, are also essential. Better processing and marketing technologies can slash postharvest losses by more than half, generating US$350 million and ensuring that 350,000 tons of additional fish will reach the poor. Improvements in marketing and market chains, expanded knowledge of business development, and market information and quality controls can boost the income of women in the fish trade. By 2015, a US$15 million investment to sustain small-scale fisheries in nine Sub-Saharan African countries would benefit 1.5 million fishing families; US$29 million more would improve the income of a million women entrepreneurs who trade in fish, with a net revenue increase of US$1.2 billion. This approach can also be applied in Bangladesh, Cambodia, Indonesia, Laos, and India for US$29.5 million **[Total investment: US$73.5 million. People reached: 32 million].**

Reducing Vulnerability to Biotic and Abiotic Stresses

Crop losses from environmental changes that lead to increased drought, flooding, and pests can be devastating. Research that helps stabilize production by reducing vulnerability to biotic and abiotic stresses is particularly beneficial to the poor, especially if resistance can be bred into the crop, replacing other expensive inputs such as irrigation or pesticides.

Controlling Wheat Rust—In 1998, severe stem-rust infections (of a race known as Ug99) were observed on wheat in Uganda and have since spread; an estimated 90–95 percent of global wheat area is susceptible to Ug99 or its new variants. Even 10 percent losses in the first 14 countries to be affected would represent more than US$10 billion annually. Combating the Ug99 infestation requires monitoring its spread for early warning and potential chemical interventions, screening released varieties and germplasm for resistance, distributing sources of resistance worldwide, and breeding to incorporate diverse resistance genes into high-yielding adapted cultivars and new germplasm to reduce potential losses, particularly for resource-poor and commercial farmers in most of Africa, the Middle East, and Asia. CGIAR centers have identified a few resistant released cultivars or advanced breeding materials, some with a 10–25 percent yield increase. The cost of addressing the threat of wheat rust during the next five years in Uganda, Kenya, Ethiopia, Sudan, Eritrea, Tanzania, Mali, Nigeria, Zambia, Mozambique, Madagascar, India, Pakistan, Nepal, Afghanistan, Iran, Egypt, Syria, and Mexico is approximately US$27.5 million, with an additional US$10 million during the next three to five years for CGIAR centers and NARS to deploy resistant-bred germplasm as a pre-emptive measure to avoid potential losses in case this disease turns into an epidemic in South America's Southern Cone, North Africa, Turkey, Bangladesh, and China. **[Total investment: US$37.5 million. People reached: 2.88 billion.]**

Developing and disseminating a vaccine for prevention of East Coast Fever in cattle—In numerous countries in Africa, East Coast Fever (ECF) is the most economically devastating cattle disease, imposing losses that exceed US$200 million annually. In addition, there is environmental damage due to the use of acaricides, which are used to control the tick vector of the disease. A successful vaccine could lead to a total milk yield increase of 243.8 million liters per year and a meat increase of 34,000 tons. Additional environmental benefits include saving 560 million liters of water and eliminating 560,000 liters of acaricide from the environment each year, which would in turn reduce water contamination, cases of human poisoning, and the mortality of nontarget organisms. All these benefits translate into increased incomes, better nutrition, and welfare improvements for approximately 20 million people. The project would involve close relationships with veterinary authorities, the African Union's Interafrican Bureau for Animal Resources, and private-sector entities. **[Total investment: US$10.5 million. People reached: 20 million, with additional indirect effects on many more.]**

Developing and disseminating drought-tolerant maize in Africa—In many parts of Africa, maize is a critical source of human food, livestock feed, and industrial raw materials. However, maize production is constrained by recurrent droughts. Drought-tolerant maize cultivars disseminated to farmers in Eastern and Southern Africa have shown a 20 percent gain in average on-farm yield. Further improvement in yield can be achieved via partnerships with NARS, seed companies, and farmers, but support to public and private breeders will require an investment of about US$1 million per year per country, for three to five years. In West and Central Africa early and extra-early cultivars adapted to the short rainy season on the fringes of the northern Guinea and Sudan savannas have shown a 100 percent increase in limited farm trials, in combination with appropriate crop-management practices. Extensive testing of the cultivars and vigorous promotion are essential for widespread adoption, and there is a need to establish effective seed systems to make high-quality seeds of the improved cultivars available to farmers in those countries that do not have well-established seed industries. These research efforts will require an investment of US$1 million per year per country, spread over three to five years. Partnerships among national maize scientists in collaboration with extension staff, nongovernmental organizations (NGOs), and the private seed companies of the pilot countries will facilitate the development and distribution of the drought-tolerant maize cultivar. **[Total investment: US$100 million over 5 years in 20 countries. People reached: 320 million, with additional indirect effects on many more.]**

Improving the Nutritional Quality of Food

Quantities of food alone do not reduce hunger and malnutrition. Energy, protein, and micronutrients are all necessary, and food-safety concerns are increasingly important for domestic consumption and trade. The CGIAR is addressing these issues by promoting dietary diversity through variety in foods (including underutilized species), breeding for micronutrients, and addressing food-safety concerns through improved handling of products.

Scaling up biofortification—An estimated 2 billion people in the developing world suffer from mineral and vitamin deficiencies, which lower disease resistance, increase mortality, compromise cognitive development, stunt growth, and lower work productivity. The HarvestPlus Challenge Program seeks to develop and distribute varieties of food staples that are high in iron, zinc, and provitamin A through a global alliance of scientific institutions and implementing agencies in developing and developed countries. The "Copenhagen Consensus" ranked biofortification as the fifth most productive investment that can be made in developing countries. Initial investments in agricultural research at a central location can generate high recurrent benefits at low cost as adapted biofortified varieties become available in country after country across time. The cost of completing the development phase of HarvestPlus (2009–2015) is an additional US$75 million beyond what has been secured, plus US$75 million for deploying rice and wheat in South Asia. The returns are enormous: biofortified rice and wheat in Bangladesh, India, and Pakistan could reach 210–420 million people per year. The disability adjusted life years saved (due to biofortification with zinc only) are valued at US$123–335 million per year. Women and children would be the greatest beneficiaries because of their greater need for micronutrients. **[Total investment: US$125 million over 5 years. People reached: up to 672 million.]**

ENVIRONMENT FOR PEOPLE: conserve, enhance, and sustainably use natural resources and biodiversity to improve the livelihoods of the poor, and respond to climate change

The CGIAR has a long history of developing technologies and practices to protect the soil, water, trees, and genetic resource base of agriculture and identifying appropriate institutions and policies to facilitate their adoption. Natural resource management (NRM) practices can reduce agricultural production costs and the use of inputs such as fertilizers and irrigation. With rising fertilizer and energy prices, these savings are especially important for the poor. Research on neglected and underutilized species can broaden the food base. This work has become even more urgent as a means of coping with climate change. Bests bets for CGIAR investments in this area are grouped around the themes of mitigating climate change, increasing the resilience of agro-ecosystems (including climate change adaptation), and increasing the efficiency of water use.

Addressing Climate Change

Climate change will make agriculture even more unpredictable than it is today. It is essential to assist affected populations to adapt to the changing conditions, including through the improved use of biodiversity, and to determine how to better manage agriculture and forest systems to mitigate climate change. Mitigation strategies consist of not only international policy frameworks, but also local-level frameworks for ecosystem service payments that provide opportunities to the rural populations to earn income from improved water flows or carbon sequestration that result from their farming and resource-management decisions.

Increasing carbon sequestration and the livelihoods of forest people— Attention has recently refocused on forests because of their linkages to climate-change mitigation and adaptation. Negotiations toward a post-2012 climate governance regime have brought reduced emissions from deforestation and degradation (REDD) to the center of the international agenda. The key issues to be addressed by research on the role of avoided deforestation in climate mitigation include the need for standardized, widely accepted, credible, and scientifically sound methodologies to measure and monitor reduced emissions from deforestation and other land-use change. To inform negotiations at the global level, research is needed on how countries with very different forest and economic conditions can engage with and benefit from a carbon-offset compensation regime. At the national level, research will inform the design and implementation of REDD schemes, taking into account institutions, land ownership and access rights, equity and benefit sharing, and the rights of indigenous peoples and local communities. A research investment of US$30 million over 10 years could help up to 30 million people in poor forest-dependent communities in Indonesia, Bolivia, Brazil, and Mexico tap into the potential US$1 billion market for REDD and reduce climatic risks to vulnerable communities, with US$15 million for extension to other countries. **[Total investment: US$45 million. People reached: 48 million people in poor, forest-dependent communities.]**

Increasing the Resilience of Agro-ecosystems

Ensuring the resilience of agro-ecosystems and rural populations to help people deal with climate change is gaining in importance. Increased resilience, together with the increased deployment of agricultural biodiversity, is also necessary to achieve improved sustainability while achieving the productivity goals identified earlier.

Conducting climate-change and adaptation research—CGIAR research on climate change and adaptation will be conducted at different scales and will examine agricultural production as well as forest systems. Global modeling will assess the impacts of climate change on food production growth, land use, and water to identify areas with significant impacts and assess broader policies and investments for sustainable growth. Spatial analysis and targeting will identify the most important biophysical constraints, investment targets, policy changes, plant exchange, and technologies for poverty-reduction and environmental impacts. Research conducted in the semi-arid tropics, one of the most fragile and vulnerable agro-ecosystems, will attempt to understand the risks of climate change to the community. Work with NARS will enhance capacity for improved soil and water management or other adaptation strategies and policy research in national programs. Finally, potential climate-change effects in the selected regions will be examined to identify and prioritize the sectors most at risk and to develop gender-equitable agricultural adaptation and mitigation strategies, including deploying crop diversity as a coping mechanism as an integral part of agricultural development in the rainfed semi-arid tropics in Asia. The research will help 500 million people in the semi-arid tropics and 236 million who depend on dry forests in Sub-Saharan Africa to decrease their vulnerability by increasing the resilience of the agro-ecological systems they depend upon. In addition to reducing vulnerability, yield gains of 20 to 30 percent are estimated and the adoption of improved NRM practices and technologies will result in carbon sequestration and improved watershed function, leading to increased smallholder incomes. **[Total investment: US$127.5 million over 5 years. People reached: 1.18 billion.]**

Improving Soil Fertility

Improved crop cultivars have little yield advantage over indigenous varieties and will not result in much production increase without addressing the fertility constraint, which is one of the greatest constraints to productivity, especially in Africa.

Combining organic and inorganic nutrients for increased crop productivity—Evidence shows that combining organic nutrients with small doses of mineral fertilizer gives the highest yields and financial returns on maize and other cereal crops across a range of African sites, and can sustainably raise crop productivity with existing germplasm—doubling per capita food availability for adopting maize households and raising incomes by $300/ha. Organic sources such as legumes (grain, nongrain, and woody), composting, and animal manure add organic matter essential to efficient fertilizer use on many African soils and provide environmental benefits. Combining this with microdosing of mineral fertilizer can give high returns, especially with water harvesting. However, it is difficult to identify the best-bet combinations for different ecological conditions and ensure that smallholders and women farmers can obtain fertilizer. Therefore, improved soil diagnostics, adaptive research, accompanying information systems, and policy and market research are also needed on ways to ensure timely access to fertilizer, for example, through fertilizer vouchers and smaller bags. Key areas for application are the semi-arid and sub-humid savannahs of Africa, but approaches are also applicable in West and Central Asia, as well as in parts of South Asia. **[Total investment: US$55 million over 5 years. People reached: 400 million.]**

Increasing the Efficiency of Water Use and the Effectiveness of Irrigation

Reliable water supplies are fundamental for stable, high-yielding agricultural production. But as the demand for water from all sectors increases, there is increasing water scarcity. On the supply side, increasingly erratic precipitation due to climate change makes it more challenging to obtain and manage water. CGIAR research on improving water management and enhancing the returns to investment in irrigation ranges from micro-level water harvesting and drip kits to management of large-scale irrigation systems. Research is essential to guide policy, institutional, and regulatory reforms to improve water governance and irrigation management—from basins to farmer-managed irrigation—and to build economic incentives in water allocation at different scales.

Promoting sustainable groundwater use in agriculture—Groundwater resources offer high productivity gains and some protection against climatic fluctuations. Hydrogeologic and economic analysis is needed to allow decisionmakers to sustainably develop groundwater in Sub-Saharan Africa and to mitigate the impacts of overuse in South and East Asia. Research in Asia will identify ways to reduce groundwater extraction without crop losses through improved policy (including energy prices), conjunctive groundwater–surface water management, agronomic management, and use of excess runoff to recharge groundwater. In SSA, there is scope to develop groundwater resources for supplementary irrigation and thus improve the livelihoods and food security of up to 30 million people, including 7.2 million poor. US$24 million over five years would be needed for the CGIAR and NARS in Sub-Saharan Africa, India, Pakistan, China, Vietnam, and Cambodia, in collaboration with advanced research institutes, to undertake modeling. **[Total investment: US$24 million. People reached: 261 million.]**

INNOVATION FOR PEOPLE: mobilize science and technology to stimulate institutional innovation and to enable policies for pro-poor agricultural growth and gender equity

Many institutions and policies play a critical role in accelerating innovation processes and translating agricultural production into food, nutrition, and livelihood security for the poor. This section highlights several key areas, including genetic resource management and strengthening markets. In many such cases, the CGIAR plays an important role in global or national policy dialogues.

Genetic Resource Management

As trustee of the world's largest collection of genetic resources, the CGIAR has a leadership role in the use of ex situ and in situ genetic resources to stabilize and expand food production. This includes mining the CGIAR genebanks for useful traits, germplasm management, and strengthening seed systems to provide improved genetic resources to small farmers.

Enhancing germplasm exchange—Because of restrictive sovereign and intellectual property rights and technologies that prevent the reproduction of seeds, the ability to use plant genetic resources for food and agriculture (PGRFA) to improve agricultural production and enhance food security has been limited. Therefore, the international community developed and adopted the International Treaty on PGRFA. The Treaty creates a common pool of PGRFA of the most important crops and forages, which is made freely available to all parties to the Treaty for research and breeding in order to meet the challenges of sustainable productivity improvement, climate change, adverse environmental impact, and improved food security. Currently, 119 countries have ratified the Treaty. CGIAR crop centers collaborate in its implementation through the CGIAR Systemwide Genetic Resources Programme. Full implementation of the Treaty will result in improved conservation and better use of plant genetic resources and will ensure improved benefit sharing and farmers' rights. An investment of US$3 million per year is required for the program's work in 16 countries during a five-year period. **[Total investment: US$15 million. People reached: global impact, with a focus in developing countries.]**

Institutional Innovation to Improve Market Access through New Methods and Linkages

As agriculture is increasingly linked to local, regional, and global markets, CGIAR research explores ways for smallholders to increase their incomes by integrating into value chains through new products, processing, and institutional arrangements, including farmers' groups and the private sector.

Improving market information and value chains—Value chains involve a complex network of assemblers, brokers, wholesalers, processors, retailers, and exporters, all working within an environment of imperfect information. A vital part of agricultural marketing chains is the processing of information on farmers' harvest areas and periods, current prices in neighboring cities, the marketing or shifting of products from one city to another at the lowest cost, technologies applied, or other product attributes valued by consumers. New information and communication technologies can help reduce the costs of linking buyers and sellers within the value chain, and improved market information systems can reduce agricultural marketing margins and price volatility and increase farm prices and marketed volumes. These improvements will raise farm income and reduce poverty. Farmers in Uganda collected an estimated 5–15 percent increase in farm-gate price thanks to access to improved market information. In India, estimates indicate that improved market information through the e-choupal program increases farm-gate prices by 2.5 percent. If the market information systems were scaled up to the national level within six countries (India, Bangladesh, Senegal, Ghana, Kenya, and Tanzania), it would lift 28 million people out of poverty. A research investment of US$10.5 million over five years will substantively improve market information systems in the six countries mentioned, with collaborative effort from the private sector and partnership with all the CGIAR centers. **[Total cost: US$10.5 million. People reached: 45 million.]**

Innovative Strategies to Ensure that Agricultural Production Benefits the Poor, Especially Women

The rapidly changing nature of global and local agricultural systems calls for new approaches to shorten the process of developing and adopting innovations. CGIAR applied research can guide organizational, management, and governance reforms to reorient public education, research, and extension organizations toward the promotion of more dynamic, responsive, and competitive agricultural sectors in the developing world. Investment in education and capacity strengthening is needed, including the use of new approaches such as distance learning and ICTs. Particular attention is also needed to ensure that women are integrated into the whole innovation system, including research institutes, extension services, and farmer organizations.

***Ensuring women's participation in agriculture*—**There is abundant evidence that women play a critical role in agriculture, and that the food and income under their control plays a vital role in meeting the basic needs of their families. Therefore, achieving food security requires overcoming the barriers that have prevented women from full participation in highly productive agriculture. The CGIAR is involved in a variety of efforts, such as working to ensure that women have secure access to land, water, animals, tools, and other assets they need for agriculture; that women's needs are addressed in agricultural research; that women are fully included in extension and innovation systems; and that they have access to postharvest processing and markets, with control of the income they obtain. A commitment to gender equity in all aspects of agricultural research and policy will ensure that the gains of agricultural productivity are translated into real welfare gains for rural households, including the reduction of child malnutrition. **[Total cost: US$30 million. People reached: 200 million.]**

***Connecting agriculture and health*—**Finally, the CGIAR is playing a leadership role in forging links between agriculture and health and is addressing the broader concerns of stakeholders and policymakers in the global agricultural, nutrition, and health communities. Research in this area will mitigate the negative effects of ill health on agricultural activities while maximizing opportunities for agriculture to benefit health and for better health to benefit agriculture. The priority areas identified by an international consultation process including the WHO and others are: 1) HIV/AIDS and agriculture; 2) avian influenza, livelihoods, and food security; 3) agriculture, nutrition, diet, and health; 4) food safety and growing food-supply chains; 5) water-borne diseases and water management; 6) occupational health in agriculture; and 7) the links between animal and human health. The ultimate goal is to undertake cutting-edge research at the intersections of agriculture and health that seeks to maximize impact on the rural poor. **[Total cost: US$75 million. People reached: global.]**

The Business Case for a CGIAR at US$1 Billion

With doubled funding of US$1 billion, the CGIAR will need to have clear priorities. It has already identified a strong set of research programs awaiting roll-out, but they are currently constrained by a lack of funds. Some significant "best bet" examples have been given in this paper. The cases are relatively large by the standards of agricultural research, but are small in terms of general development investment program sizes. They are, however, truly large in terms of people reached and returns to investment: the "best bet" examples described would benefit billions of people.

Under current CGIAR center programming, however, these "best bets" and the more comprehensive listing of "best bets" in Annex 2 are only partially funded, and there is heavy reliance on restricted funding, which reduces the efficiency of implementation because of a lack of continuity and staffing. With doubled funding, the centers could fully implement these and other "best bets" as well as the needed core activities of germplasm storage, maintenance breeding, and other essential support programs, and could also expand frontiers in essential areas of new agricultural science and policy, such as biotechnology, information systems, and nanotechnology.

A reformed and more efficient CGIAR will not only help increase productivity, improve the natural-resource base, and strengthen policy and institutions through its own research, but will also be better able to link with private-sector innovation and end user–oriented operations, which would yield high pay-offs to development assistance investments.

Annex 1

Some Examples of Recent, Major CGIAR Research Contributions

This list of some recent CGIAR achievements is based on peer-reviewed impact studies, science prize awards, and international consensus-seeking exercises such as the Copenhagen Consensus for prioritizing pro-poor development investments. For clarity, the contributions have been arranged into three categories: technology, natural resources and environment, and institutions and policy.

I. Technology

Wheat and rice breeding

As described earlier in this paper, the CGIAR's innovative rice-breeding research has had a tremendous impact around the world. It has also received two World Food Prizes:

1996: Dr. Henry Beachell and Dr. Gurdev Khush (IRRI) received the World Food Prize for their revolutionary work to greatly improve the yield potential of rice. The developed rice genetic lines and varieties more than doubled the world's rice production in three decades.

2004: Dr. Monty Jones (WARDA) received the World Food Prize for his pioneering effort to develop New Rice for Africa (NERICA), which recaptured the genetic potential of ancient African types of rice.

Genetic improvement of potato

CIP has played a significant role in sharing and distributing elite disease-resistant germplasm. A CIP-related drought- and virus-tolerant variety disseminated in northern China showed a varietal productivity gain conservatively estimated to be 3 mt/ha. The internal rate of return (IRR) to investment was estimated at 15 to 17 percent from 1972 to 2010.[18]

1990: Dr. John Niederhauser (CIP's founder) received the World Food Prize for the discovery of a durable resistance to the potato late blight disease, which boosted the food supply for many nations.

Improved tilapia strain

The Genetic Improvement of Farmed Tilapia (GIFT) strain developed by the World Fish Center has generated additional income and employment in many Asian countries. In the Philippines, almost 300,000 people benefit directly or indirectly from employment in the tilapia industry. With lower costs of production and higher yields, poor consumers have also enjoyed lower market prices. The development and dissemination of GIFT generated an IRR of more than 70 percent from 1998 to 2010.[19]

2005: Dr. Modadugu V. Gupta (WorldFish Center) was awarded the World Food Prize for his pioneering research to uncover new aquaculture technologies specifically targeted to the poor. He was the first to recognize the potential of a million untapped water bodies in Bangladesh as a resource for growing fish, unlocking the latent productivity of abandoned ponds, roadside ditches, and seasonally flooded fields. His work was instrumental in developing international fish biodiversity protocols and policies across many countries in Asia, Africa, and the Pacific.

II. Natural Resources and Environment

Zero tillage in India

Zero tillage (ZT) in India not only eliminated tillage costs but also reduced the number of field operations from an average of seven to one; reduced water usage by about 1 million liters per hectare (a saving of 20–35 percent); improved soil structure, fertility, and biological properties; typically reduced the incidence of weeds; improved the population dynamics of certain wheat pests and diseases; and increased wheat yields by 6–10 percent and reduced production costs by 5–10 percent. Conservative estimates show that the ZT R&D program (initiated by CIMMYT and the Rice Wheat Consortium) yielded a net present value of US$94 million, equivalent to a benefit–cost ratio of 39 and an IRR of 57 percent. Assuming a more optimistic scenario, the IRR rises to 66 percent.[20]

Fertilizer trees rejuvenating soils in Southern Africa

Improved tree fallows provide better food security and enhanced soil health and at the same time reduce water runoff and soil erosion. A 0.20-hectare tree fallow added 57–114 extra person-days of maize consumption per year. Fertilizer trees also improved soil fertility, soil aggregation, water infiltration, and water-holding capacity. On average, an additional 11 percent of fuelwood was available, potentially reducing tree felling in nearby forests. In addition, fertilizer trees also increased carbon sequestration by an estimated 2.5–3.6 mt/ha.[21]

2002: Dr. Pedro A. Sanchez (ICRAF) was awarded the World Food Prize for pioneering ways to restore fertility to the poorest and most degraded soils in Latin America and Africa. This major contribution to preserving delicate ecosystem also offered great hope to those struggling to survive on marginal lands around the world.

Biodiversity protection

Maintaining the genetic richness of crops and varieties is of key importance in meeting the livelihood needs of resource-poor farmers in many parts of the world. Bioversity's participatory plant breeding aimed at improving local crop varieties contributes to the maintenance of high levels of local crop diversity. In Nepal, this breeding strategy was used to develop a new improved rice variety based on a traditional high-quality aromatic variety, but with improved resistance to leaf and neck blast. In Botswana, Kenya, Senegal, Tanzania, and Uganda, stimulating the use of nutritionally rich dark green leafy vegetables played a role in reducing the occurrence of xeropthalmia and other deficiency diseases. In Nairobi, this work has increased sales of traditional leafy vegetables by 1,100 percent in two years.[22] In 2005, the project was awarded a World Food Day medal by FAO.

III. Institutions and Policy

"Food for Education" (FFE) Program in Bangladesh

The FFE program in Bangladesh was an outstanding success, leading to 20–30 percent increases in school participation rates and retaining students in school for 0.4–1.4 years longer than expected. Owing to improved school attendance and duration, girls who participated in the FFE program could expect to increase their lifetime earnings by 33–35 percent, and boys by 11–18 percent. The increases in earnings suggest a return to investment of between 18 and 26 percent for the Government of Bangladesh and the U.S. Agency for International Development (USAID). The return to investment of US$151,000 as a result of IFPRI's involvement in the program was conservatively estimated at 64–96 percent.

Childhood nutrition affects adult productivity

An IFPRI-led study found that Guatemalan boys (but not girls) who received a high-energy, high-protein supplement in the first two years of life earned on average 46 percent higher wages as adults, and boys who received the supplement in their first three years earned 37 percent higher wages on average, compared with boys who did not receive the supplement. After age three, the nutritional supplement had no effect on hourly wages, implying that young children have specific nutritional needs that must be met at specific times. The results suggest that improving the nutrition of very young children can help break the intergenerational cycle of poverty and hunger.[23]

2001: Dr. Per Pinstrup Andersen (IFPRI) was awarded the World Food Prize for initiating the research effort that enabled several governments to reform their food subsidy programs, dramatically increasing food availability to the most poor. He also initiated a global effort to uplift the most vulnerable people by formulating IFPRI's 2020 Vision Initiative. This initiative has alerted world leaders to potential crises in food-security issues, helped reverse the trend of decreasing global developmental assistance, and led to actions that have brought about significant reduction in world hunger and poverty levels.

Early childhood intervention and targeting for combating malnutrition in poor communities

Another IFPRI study on the impact of food assistance and behavior-change communication on childhood undernutrition in Haiti compared preventive approaches that targeted all children 6–24 months of age with recuperative approaches that targeted undernourished children less than 5 years old. It found that in communities receiving the preventive approach, the prevalence of stunting, underweight, and wasting after three years was 4, 6, and 4 percentage points lower, respectively, compared to communities receiving the recuperative program approach. Mean height-for-age, weight-for-age, and weight-for-height Z-scores were also significantly higher in the preventive compared to the recuperative program communities. The findings suggest that the pathways of impact, which led to better child nutritional outcomes among preventive communities, operated mainly through changes in the child-care context resulting from participation in the program and through greater availability of the fortified food to children in the preventive approach.[24]

Annex 2
CGIAR "Best Bet" Programs

This list of high-priority research is based on submissions from CGIAR centers, which were asked to identify topics under the CGIAR's new Strategic Priorities. In some cases, similar submissions by two or more centers have been merged. Selected "best bets" and an overview of each group are described in the main body of this paper.[25]

Food for People

Improving productivity

- Raising productivity though high-volume trials of locally adapted bean and legume varieties
- Improving root-crop and cereal production through breeding programs and distribution to improve yields and reduce environmental degradation
- Raising the ceiling and closing the yield gap in rice through improved crop and post-harvest management, cultivar selection, and small-scale mechanization
- Promoting sustainable, small-scale fisheries to generate income and improve nutrition
- Genetically improving fish to aid poor farmers in improving nutrition and reducing poverty

Reducing vulnerability to abiotic and biotic stress

- Developing and disseminating drought-tolerant cultivars to replace outdated, poor-performing strains
- Containing major plant and animal diseases through vaccines, breeding, and dissemination
- Controlling weed infestations and invasive species

Improving nutritional value

- Biofortifying crops to improve vitamin and mineral deficiencies in chronically malnourished populations

- Introducing integrated aquaculture-agriculture to smallholders and promoting market-oriented enterprises for expanded fish production
- Using neglected and underutilized crop species to augment incomes and strengthen livelihoods

Improving livestock productivity through improved feeds

- Planting resilient, nutritious, and environmentally beneficial fast-growing shrubs for dairy cows and goats in drought-prone areas
- Empowering communities through climate-change mitigation using integrated feed-resource management
- Improving crop-residue fodder value through the adoption of advanced food-feed crop varieties

Environment for People

Mitigating climate change

- Using REDD to involve local communities in reducing carbon emissions and increasing biodiversity
- Providing incentives and strategies for the delivery of environmental services to facilitate sustainable agriculture
- Developing micropayment mechanisms for smallholder carbon sequestration in agroforestry projects
- Developing local bioenergy through community-based solutions to facilitate environmental sustainability

Increasing resilience of agro-ecosystems

- Encouraging farmer and smallholder adoption of natural resource management to facilitate adaptation to climate change and to improve agro-ecosystems
- Researching and promoting regionally tailored integrated farming systems to preserve biodiversity and stabilize livelihoods

- Promoting policies of integrated soil management and innovative fertilizer usage to improve yield
- Adopting integrated pest management to augment or restore agriculture production and value
- Enhancing the adoption of natural resource management practices and institutions through participatory approaches
- Securing and using the diversity of crop wild relatives to provide enhanced adaptability and resilience to climate change

Improving water-use efficiency (water management)

- Developing and sustaining water resources to aid in adaptation to climate change and effects of globalization on small-scale farmers

Innovation for People

Governing genetic resources

- Promoting genetic resource management through knowledge exchange, experimentation, and institutional leadership
- Unlocking the potential within CGIAR gene banks to address emerging challenges
- Using genetic resources to strengthen local capacity and improve production for small farmers

Improving market access through institutional innovations and linkages

- Improving small-scale traditional milk value chains through training and certification
- Providing high-yielding cassava for industrial processing
- Improving market information systems

Ensuring that agricultural production benefits the poor, especially women

- Strengthening capacity for food production policy and strategy
- Revitalizing agricultural knowledge and innovation systems to meet changing needs and accelerate the release and adoption of new varieties through institutional and organizational reforms in public research and regulatory systems
- Enhancing rural women's control of assets to improve household livelihoods
- Promoting the CGIAR initiative in forging links between agriculture and health

Notes

1. Note that these are only selected examples among many valuable programs. Because of differences in computing the number of people reached and the extent of impact, per capita expenditure calculations are not comparable.
2. CGIAR Science Council. 2006. *Impacts of international wheat breeding in the developing world.* Science Council/Standing Panel on Impact Assessment Brief Number 7. Rome: CGIAR Science Council.
3. M. Hossain, D. Gollin, V. Cabanilla, E. Cabrera, N. Johnson, G. S. Khush, and G. McLaren. 2002. International research and genetic improvement in rice: Evidence from Asia and Latin America. In R. Evenson and D. Gollin (eds.), *Crop variety improvement and its effect on productivity: The impact of international agricultural research.* Wallingford, U.K.: CABI.
4. E. Somado, R. Guei, and S. Keya (eds). 2008. NERICA®: *The New Rice for Africa—A compendium*. Cotonou, Benin; Rome; and Tokyo: Africa Rice Center; Food and Agriculture Organization of the United Nations; and Sasakawa Africa Association.
5. For how CGIAR centers and NARS have worked together to generate synergy or multiplier effects, see S. Fan, C. Chan-Kang, K. Qian, and K. Krishnaiah. 2005. National and international agricultural research and rural poverty: The case of rice research in India and China. *Agricultural Economics* 33 (suppl. 3): 369-79.
6. All research spending data are from Agricultural Science & Technology Indicators (ASTI) and are measured in constant 2005 U.S. dollars. This is different from the measure of purchasing power parity (PPP) or international dollars reported by various ASTI reports. We use actual (2005) US$ for easy comparisons with development aid and other public expenditures.
7. N. M. Beintema and G. J. Stads. Forthcoming. Measuring agricultural R&D investments: A revised global picture. Agricultural Science & Technology Indicators (ASTI) background note. Washington, D.C.: IFPRI.
8. The share of CGIAR spending is 4 percent when agricultural R&D spending is measured in purchasing-power parity dollars; see Beintema and Stads, forthcoming.
9. For comparisons of returns to different types of investment, see S. Fan. 2008. *Public expenditures, growth, and poverty: Lessons from developing countries*. Baltimore: Johns Hopkins University Press.
10. The economic principle behind this simulation is that R&D resources can be allocated until the marginal returns of these investments are equal. If there is a difference in returns, resources can be moved from lower-return regions to higher-return regions. When returns

are equal among regions, total sum benefits from all regions are maximized.

11. The CGIAR reports its spending for Sub-Saharan Africa, Asia, Latin America, and WANA. In order to determine CGIAR spending for each subregion, we use the share of NARS spending.
12. We use the following weights to construct the R&D stock from each of the past seven years of agricultural research investment: 0.05, 0.10, 0.20, 0.30, 0.20, 0.10, and 0.05. In general, production elasticities of R&D stock in the literature range from 0.17 to 0.25. Based on a literature survey, we use 0.15 for African regions, 0.18 for South Asia, 0.2 for Southeast/East Asia, 0.1 for Latin America, and 0.1 for WANA. These elasticities are the best approximations for the various regions and are consistent with various rates of return studies.
13. Due to the unavailability of agricultural research spending data for 2008, we use the annual growth rate from 1992 to 2000 to project spending to 2008, which is our baseline. We then assume the spending level will be doubled within five years (from 2008 to 2013), with each region receiving at least the minimum additional investment based on past trends. After 2013, spending will continue to grow at the baseline rate.
14. For agricultural output-poverty elasticities, the range for Asia is between -0.65 and -1.2. For Sub-Saharan Africa, it varies from -0.27 to -1.83. For Latin America, the elasticity is around -0.02 to 1.32. From this, we derive the poverty-output elasticities: -1.78 for Africa, -1.0 for Asia, -0.5 for LAC, and -0.5 for WANA.
15. A similar approach to obtaining optimal input allocations is used by S. Fan, X. Zhang, and S. Robinson. 2003. Structural change and economic growth in China. *Review of Development Economics* 7 (3): 360–77. More specifically in our simulation, the first optimization problem maximizes the sum of the log of output of the different regions weighted by the share of each region in total agricultural output, subject to a Cobb-Douglas production function for each region using five inputs (land, labor, fertilizer, tractors, and animal stock), which we fix at their initial level, and the stock of R&D. The optimization problem is solved each year from 2008 to 2020, taking into consideration the changes in regional R&D stocks from previous years. The R&D stock is exogenously increased due to the changes in research investment as described in footnote 11. The second optimization problem minimizes the log of the number of poor people in the different regions, weighted by the share of each region in the total number of poor. This problem uses the same production functions used in the output.

16. FAO (Food and Agriculture Organization of the United Nations). 2008. Hunger on the rise: Soaring food prices add 75 million people to global hunger rolls. Briefing paper, September 17. Available at www.fao.org/newsroom/common/ecg/1000923/en/hungerfigs.pdf.
17. Under the baseline scenario, total global annual investment requirements would amount to US$14.3 billion measured in 2008 U.S. dollars. Under the very high investment scenario, requirements would basically double to US$28.5 billion per year.
18. CGIAR Science Council. 2006. *CIP's contribution to the genetic improvement of potato.* Science Council/Standing Panel on Impact Assessment Brief Number 5. Rome: CGIAR Science Council.
19. CGIAR Science Council. 2006. *Improved tilapia benefits Asia*. Science Council/Standing Panel on Impact Assessment Brief Number 6. Rome: CGIAR Science Council.
20. CGIAR Science Council. 2006. *When zero means plenty: The impact of zero tillage in India*. Science Council/Standing Panel on Impact Assessment Brief Number 13. Rome: CGIAR Science Council.
21. CGIAR Science Council. 2006. *Fertilizer trees: Rejuvenating soils in southern Africa.* Science Council/Standing Panel on Impact Assessment Brief Number 16. Rome: CGIAR Science Council.
22. Bioversity International. 2006. Kenyans flock back to traditional leafy vegetables. News article, March 17. Available at www.bioversityinternational.org.
23. J. Hoddinott, J. Maluccio, J. Behrman, R. Flores, and R. Martorell. 2008. Effect of a nutrition intervention during early childhood on economic productivity in Guatemalan adults. *The Lancet* 371 (9610): 411–16.
24. M. Ruel, P. Menon, J.-P. Habicht, C. Loechl, G. Bergeron, G. Pelto, M. Arimond, J. Maluccio, L. Michaud, and B. Hankebo. 2008. Age-based preventive targeting of food assistance and behaviour change and communication for reduction of childhood undernutrition in Haiti: A cluster randomised trial. *The Lancet* 371 (9612): 588–95.
25. More information on each of these is available in *"Best bets" for high-impact agricultural research: Submissions by CGIAR centers.* To obtain the document, please contact Ruth Meinzen-Dick (r.meinzen-dick@cgiar.org).

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CGIAR Centers

Africa Rice Center *(WARDA)*
www.warda.cgiar.org

Bioversity International
www.bioversityinternational.org

CIAT *(Centro Internacional de Agricultura Tropical)*
www.ciat.cgiar.org

CIFOR *(Center for International Forestry Research)*
www.cifor.cgiar.org

CIMMYT *(Centro Internacional de Mejoramiento de Maiz y Trigo)*
www.cimmyt.org

CIP *(Centro Internacional de la Papa)*
www.cipotato.org

ICARDA *(International Center for Agricultural Research in the Dry Areas)*
www.icarda.cgiar.org

ICRISAT *(International Crops Research Institute for the Semi-Arid Tropics)*
www.icrisat.org

IFPRI *(International Food Policy Research Institute)*
www.ifpri.org

IITA *(International Institute of Tropical Agriculture)*
www.iita.org

ILRI *(International Livestock Research Institute)*
www.ilri.org

IRRI *(International Rice Research Institute)*
www.irri.org

IWMI *(International Water Management Institute)*
www.iwmi.cgiar.org

World Agroforestry Centre *(ICRAF)*
www.worldagroforestrycentre.org

WorldFish Center
www.worldfishcenter.org

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