An Assessment of Technology Development from the Green Revolution to Today

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Abstract

During the late 1960s/70s, the Green Revolution drew the entire world's attention to the power of new technologies to accelerate agricultural development. Massive famines, considered inevitable by some, were avoided just in the nick of time through the hard work and dedication of international and national researchers working closely with government officials, agricultural ministries, extension services, non-governmental organizations, and related agencies.

This success story remains one of the shining achievements of our time. But the very architects of that revolution cautioned the world not to take it for granted, that it would be difficult if not impossible to repeat. While the Green Revolution had bought time, it could not derail the collision course between population growth and food production.

After the initial production leap due to the Green Revolution, the 1970s/80s were a period of steady but less dramatic progress, as researchers consolidated the gains of the high-yielding varieties by improving their resistance to abiotic and biotic stresses, their eating quality, and their agronomic traits, and assisted national programs in furthering their extension to the farm.

With the food problem seemingly under control, the world's attention shifted to other issues such as environmental degradation, social equity, and poverty. Some even became suspicious of the Green Revolution, providing some evidence that wealthier farmers with larger, high-quality landholdings and access to inputs were more able to capitalize on the new technologies, leaving the rural poor further behind than before.

In response, researchers were asked to address the very challenging objectives of using technology to improve equity, decrease gender gaps, and bias benefits towards the poorest of the poor living in marginal production areas. In many ways these issues were more difficult to deal with than the original Green Revolution technologies, and the gains were likely to be much less dramatic and slower in coming. Despite these initial doubts, impacts in these areas are now emerging as substantial and well targeted towards poverty reduction.

At present, many are pinning their hopes on biotechnology and information/communication technology to provide another major jump in production comparable to the Green Revolution. At the same time, there is an increasing realization that with the globalization of agriculture, commodity prices are likely to decline and efficient production will be the key to survival in agriculture, as in other industries. Inefficient producers and production systems will fall by the wayside. The future may lie in adapting the cropping systems to environmental diversity, making the most of the different natural resources endowments of different agro-ecozones rather than homogenizing the environment through costly inputs.

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The Green Revolution — what and how

It is difficult to express superlatives that adequately convey the significance of the Green Revolution for humanity. If it had not occurred, an extra billion people would be hungry today (Conway and Toenniessen, 1999). It enabled productivity enhancements that doubled global production of the major cereal grains, causing prices for these staples to decline by more than 70 % in real terms since the 1970s. This global benefit was of special value to the poor, who spend a higher proportion of their incomes on food than do the wealthy.

The origin of the Green Revolution can perhaps be traced all the way back to the 1940s, when US Vice President Henry Wallace, a maize grower himself and former Secretary of Agriculture, persuaded the Rockefeller Foundation to add agricultural research to its agenda for helping less-developed nations, particularly to find ways of raising crop yields.

The Rockefeller Foundation sent a small team of agricultural researchers to Mexico in 1945 led by Norman Borlaug, who successfully developed the shorter, much higher-yielding wheat varieties that markedly increased wheat production around the world in subsequent decades. I would like to call special attention to the scientific contribution of Japan, because the Japanese wheat variety 'Norin 10' was the source of the dwarfing gene that researchers at Washington State University and later Borlaug's team used to reduce plant height.

Rice researchers such as Peter Jennings and Hank Beachell achieved similarly spectacular success by breeding semi-dwarf indica rices, made possible through the support of both the Rockefeller and Ford Foundations when they established and provided funding to the International Rice Research Institute (IRRI) from 1960 onwards. The world-leading rice knowledge base assembled by Japanese researchers contributed substantially to the achievements of IRRI and its partners over the years.

The press memorably dubbed the impact of the miracle wheats and rices as the " Green Revolution". Dr. Borlaug was awarded the 1970 Nobel Peace Prize in recognition of his enormous contribution in helping developing countries avoid the massive famines that were predicted by leading pundits and strategists of the day (Tribe, 1991).

Convinced by these high-payoff investments, these Foundations sought broader international participation. The UN's Food and Agriculture Organization and United Nations Development Programme, and the World Bank led by Robert McNamara proposed the formation of a global consortium of nations to contribute to the cause — resulting in the birth of the Consultative Group on International Agricultural Research in 1968.

History has proven the wisdom of this global investment. James Wolfensohn, President of the World Bank, characterized the CGIAR as "one of the most successful partnerships in the history of development in terms of scientific advances, training and capacity building, and agricultural development" (Shah and Strong, 1999). A major independent review of the CGIAR system in 1998 concluded that "there can be no long-term agenda for eradicating poverty, ending hunger, and ensuring sustainable food security without the CGIAR."

While acknowledging their role, it is important to emphasize that the Green Revolution was by no means an accomplishment of these international centers alone. It would never have occurred without the strong actions of national and local governments and research and development agencies, as well as NGOs and the private sector. Tribe (1994) lauds M. S. Swaminathan's role in India and cites Norman Borlaug's praise for that country's national research system, which Borlaug stated was "largely responsible for the wheat revolution in India".

Outcomes of the Green Revolution

Return on Green Revolution research investments

In global terms, the Green Revolution doubled the production of rice and wheat between 1960 and 1990, including a 37% increase in per capita production (McCalla, 1998). Even the developed countries benefited handsomely as they adopted and adapted these new plant types to their own temperate-zone environments. The added value of production to the United States, for example was estimated to exceed $3.4 billion from 1970 to 1993 (Conway and Toenniessen, 1996).

The astounding impact of the Green Revolution prompted many economists to examine its causes and lessons in detail. A recent study by the Asian Development Bank (2000) found that its research-for-development investments have consistently yielded a greater return than direct subsidies to agriculture. Rates of return ranged from 20 to 60 %, which is well in excess of returns for non-research investments. It also found that the inclusion of a research component in agricultural development projects increased the chances of success of such projects.

A comprehensive meta-review of 628 case observations from 294 publications on agricultural research and extension found an average rate of return on investment of 48% (Alston *et al.*,1999, cited in Asian Development Bank 2000). This is an impressive return by any standard. At ICRISAT, we found that our top 20 research themes were generating internal rates of return averaging 39 % by 1994 (Kelley *et al.*, 1995).

Economic studies found that the Green Revolution's benefits extended even beyond the lofty objective of feeding the teeming masses of poor. They demonstrated that agricultural development was functioning as an "engine of economic growth" that broadly reduces poverty. Much of the economic surplus generated by increased productivity was being spent on other goods and services — helping developing countries diversify their economies beyond agriculture, and feeding back benefits in terms of greater accessibility of goods and services such as education and health care.

Expressed at the human level, many of us who grew up in poor rural households know that farm families have long viewed increases in farm income as a way to help our children get a better education and a good job in the city, escaping the cycle of rural poverty.

From this mass of evidence, it is clear that investment in agricultural research during the Green Revolution era yielded, and continues to yield very attractive returns to development investors.

Poverty and hunger reduction

Ironically, the stunning achievements of the Green Revolution were perhaps never fully appreciated by the world community, because its very success saved the planet from experiencing the horrible consequences of mass starvation. The irony goes even further, because the enhanced productivity combined with protective policies and subsidies contributed to a food glut in the developed countries that caused many living in those fortunate circumstances to think that the world food problem had become one of excess, not shortage.

But this was clearly an illusion. As noted by Serageldin and Persley (2000), "The paradox is that despite the increasing availability of food, there are about 840 million people, or 13 % of the global population, who are food-insecure." This food insecurity is concentrated in developing countries, with a regional breakdown led by Asia in both numbers and proportions (48 % food-insecure), followed by Africa (35%) and Latin America (17%).

The root of this paradox is poverty. The poor simply cannot afford to buy the food they need (Tribe, 1994). Even subsistence farmers must purchase significant portions of their annual food supply. Although the Green Revolution dramatically reduced food prices, huge numbers of poor still live on the edge of despair. It became clear that the CGIAR needed to retarget its goals towards poverty reduction (CGIAR, 1997). This

required a clearer understanding of whom the poor are, and the marginal environments in which they live.

Equity

Studies have disagreed on the equity consequences of the Green Revolution (Tribe, 1994). Some argue that it caused the rich to get richer, and the poor, poorer. Cases have been reported where modern varieties led to mechanization that displaced labor, and forced smallholders to sell out to larger landowners. But other studies, particularly of rice farmers in the Philippines and wheat farmers in the Punjab of India, found the opposite —that employment was stimulated, that economic gains occurred across income levels, that landholdings remained as before, and that add-on economic benefits to rural villages spilled back to further benefit farm families.

No doubt both realities have some truth to them. It would have been unreasonable to expect such a fundamental advance to have only simple, uniform consequences for all. In some cases, progressive farmers took advantage of the new technology more aggressively than did their neighbors, and their advantage was enhanced if they had greater access to land and capital. In other situations, where these advantages were absent and/or greater social cohesion and legal structures bound farmers to a collective destiny, the benefits were more equally shared. One should be cautious in making value judgments about these outcomes — both can be seen in strongly positive lights, as well as carrying their own drawbacks.

After the Revolution – a broadened agenda

Like the NASA space program, over time the glittering achievements of the Green Revolution came to an accepted as an everyday reality, and the world began to ask, "what next?" The CGIAR was urged to expand its agenda to solve poverty, hunger, equity, and environmental problems.

Wolf (1986) admirably summarized the mood of the time, the tasks left undone, and the broadening of the agenda. He pointed out that many subsistence farmers on rainfed lands were yet to benefit from improved varieties, especially in Africa. The Green Revolution varieties, bred to respond to good soil fertility, water supply and pest control, were not advantageous under more stressful conditions. A quarter of the world's people and agricultural lands had missed the Green Revolution party. In India, for example, long associated with the Green Revolution, there remained 184 million rural poor in 1993, of which 84 % lived in less-favorable, rainfed areas, accounting for 40% of total agricultural output (Asian Development Bank, 2000).

These marginal areas and neglected peoples were the source of rapid population growth and environmental degradation and should now become the prime targets for rural development, Wolf argued. But these farmers could not afford, nor would it be environmentally wise for them to adopt the high-input packages of the Green Revolution. Much could be learned from their traditional practices based on more ecologically friendly principles such as shifting cultivation, intercropping, and tailoring the crop and crop management system to local conditions, rather than homogenizing the environment to suit the highly-bred crop.

Even in advance of this global awakening, the CGIAR had increased its investment in research targeted towards marginal environments, including the creation of our Center, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and our sister Center ICARDA (the International Center for Agricultural Research in Dry Areas). Other sister Centers also increased their attention to marginal rainfed environments and peoples. And several more Centers were added to the system to focus on a broader range of ecological issues and approaches, including agroforestry, forestry, water, fisheries, and livestock.

Marginal environments – a wise investment?

The wisdom of relative investments in favorable versus non-favorable or marginal environments has been a controversial issue since the mid-1980s. The Green Revolution experience taught that more favorable areas generated larger responses to inputs at lower costs per unit output. But partly as a result of the long-standing priority accorded to those favorable areas, many of the readily obtainable gains had already been achieved there. Returns to productivity research in favorable areas are beginning to level off or even decline, as sustainability issues confront some key areas such as the high-yielding rice-wheat systems of the Indo-Gangetic Plain of South Asia.

Progress in the more difficult marginal areas has, understandably, taken decades to bear fruit. But it is often forgotten that the impact of the Green Revolution gained traction not earlier than two decades after Rockefeller's initial investment in Mexico. In only a slightly greater time frame, CGIAR and partners' investments in marginal lands are now beginning to pay off handsomely, despite the greater complexity of the challenges and harsh variability of the environments.

Recent evidence such as the econometric analysis of district level data in India by Fan and Hazell (1999) is revealing that carefully targeted investments in marginal areas are delivering comparable or even greater returns than in favored areas. A recent study by the Asian Development Bank (2000) concluded that "Investments in infrastructure, agricultural technology and human capital are now at least as productive in many rainfed areas as in irrigated areas and have a much greater impact on poverty alleviation."

For example, even small "micro"—doses of inorganic fertilizers combined with local sources of organic matter and simple tied ridging to enhance on-site water retention can give large and profitable cereal yield increases in the semi-arid tropics of West Africa (Sanders *et al.*, 1996). Yields of millet, the zone's most extensively grown cereal, can be doubled or even tripled through tiny applications of phosphorus and nitrogen, even in these hot, dry, sandy soils (Bationo and Lompo, 1999). Contrary to conventional wisdom, correction of fertilizer deficiencies with small doses in such environments reduces rather than increases farmers' risk by improving crop vigor and hastening maturity to better escape drought.

Not only cereals, but improved food legume varieties are being enthusiastically adopted in dry marginal areas. Shortening the crop growth cycle by a third or more for pigeonpea and chickpea enabled them to be inserted as a second crop before or after cereals in the dry tropics of South Asia, substantially raising farmers' net incomes while diversifying their operations and making them more sustainable (Bantilan and Parthasarathy, 1999; ICRISAT, 1996).

Gender equity

The achievements of the Green Revolution also fostered hopes that agricultural development could be more specifically targeted towards the more disadvantaged people within society, particularly women and children. Tribe (1994), citing a World Health Organization report, summarized the dilemma faced by women. They constitute only one-third of the world's work force, yet they work two-thirds of the total hours, for which they receive only 10% of the total income, and own less than 1% of the total property.

Although not consciously targeted, researchers found that many effects of the Green Revolution were positive for women. Paris (1998) reported that the new varieties increased the demand for female hired labor because of more intensive crop care requirements. Weeding, harvesting and postharvest operations were found to be activities that employed more women than men.

Similarly, the adoption of improved groundnut production technology packages significantly increased the use of female hired labor, and helped to provide new income channels through "task specialization" (Kolli and

Bantilan, 1997). As examples, the introduction of chickpea in the "Barind" zone of northwestern Bangladesh provided a new income stream for women who harvest the top twigs for consumption as a fresh vegetable (ICRISAT, 1996). And early-maturing pigeonpea varieties in Kenya are enabling women's cooperative members to harvest high-value green peas for fresh-frozen export to the UK, earning a high income (ICRISAT research in progress).

Kolli and Bantilan (1997) found that women also highly value reductions in drudgery and occupational hazards, in addition to enhanced income. This illustrates the need to take a broader view of poverty than simply economic advancement.

Partnerships

The broadening of the CGIAR's agenda during the late 1980s/1990s put major strains on its capacity to deliver. Funding had not increased in proportion, and many thought that the system's reach now exceeded its grasp.

The same pressures to broaden the agenda befell national research programs. Soon these international and national organizations realized that they would have to greatly expand their partnerships, as it became clear that no single organization could fully address the complexity of the new agenda.

As a result, partnerships among international, regional, national, public and private, governmental and non-governmental organizations grew rapidly in number, diversity, and scope during the past decade. Steadily, the array of global, regional, national, local, public and private institutions engaged in agricultural research and development are interlinking themselves in an ever-tighter fabric of partnerships, sometimes characterized as "a fragile web."

The closest partners for the CGIAR system remain the government research and development agencies responsible for national priorities in the agricultural sector. We are also seeing a rapid strengthening of partnerships with non-governmental organizations (NGOs) and the private sector. Being closely focused on near-term impact, these partners are helping us and our national research colleagues translate our findings quickly into impact on the ground. It is a symbiotic relationship — they depend on research organizations as a source of new technologies, and we depend on them to tailor these to fit national and local needs and share them with farmers — and very importantly, to feed back to us the needs and priorities voiced by farmers, so we can better guide our research agenda.

As an example of the dynamism and evolution of these partnerships, the private breeding industry in India has recently begun contributing funds to ICRISAT's applied plant breeding work, without any intellectual property or germplasm restrictions and without constraining the research priority set. They have come to realize that "a rising tide lifts all boats" — that they, as well as others, stand to gain from advances in public-sector knowledge and genetic materials. Our sister Centers CIAT and CIMMYT have also garnered support from the private sector in Latin America.

The amounts of these contributions are modest, and will not be able to come close to replacing public-sector investments. And the private sector's main focus will continue to be on cash crops, rather than the orphan crops of the poor that we concentrate on. Nevertheless, we view these tangible signs as an important vote of confidence in these partnerships, boding well for the future.

After the Revolution: public attitudes towards agricultural research-for-development

In some ways, the choice of the label "Green Revolution" was unfortunate, because it caused the public to expect a continuing series of spectacular miracles rather than the steady, painstaking progress that is the more realistic outcome of research-for-development (Tribe, 1994). There is a convincing body of evidence that steady progress and massive benefits to the poor have continued since the glory days of the Green Revolution, yet this progress no longer captures the public imagination in the way that those earlier achievements did.

Between 1980 and 1990, agricultural development investments as a percentage of total world development assistance fell from 20% to 14% (Tribe, 1994 citing IFPRI), and continued to decline in the 1990s. Developed countries, once alarmed by the impending calamity of global famines and haunting, skeletonized faces of starving babies cast across their TV screens during the nightly news, have now turned their attention inward on their own economic problems and development objectives. As succinctly stated by former US President Richard Nixon, "there are no damn votes in foreign aid."

Developed countries need to realize that spillover benefits to their own agricultural prosperity from research carried out in the developing world have far exceeded their investments in it (Pardey *et al.* 1996; Tribe, 1991). The giver has been truly gifted back many times over. And far from posing a competitive threat, by helping the poor escape poverty they will be creating vast new markets for their own export goods.

The Future Harvest Organization reports that every dollar invested by the United States in international wheat research from 1960 to 1993, returned up to 200 times that amount to US farmers and consumers, for a total of up to US $ 13.4 billion. One of our ICRISAT chickpea lines is having major impact in Canada, helping save rural communities in the process. Many other examples could be cited.

Nor are the developing countries according sufficient priority to this topic. For the period 1981-85, Tribe (1994) estimated that developing countries invested only about 0.41% of the value of their agricultural gross domestic product in agricultural research, less than a fourth of the typical 2% investment made by developed countries.

Developing country leaders, motivated by needs for urban political support, sometimes choose shortsighted policies that penalize the agricultural sector by keeping food cheap through subsidized imports. If these subsidies were instead invested in research to increase the productivity and competitiveness of their own farm communities, they could obtain cheap food internally while generating employment and enabling agriculture to serve as an engine of national economic growth, benefiting the urban population as well.

To rekindle the fire of the Green Revolution, the global agricultural sector will need to articulate in modern, compelling terms the "best-kept secret" of the enormous benefit the world has enjoyed from its investments in agricultural research-for-development.

Towards this end, for example the CGIAR system recently agreed to preface itself with the more evocative name of "Future Harvest Centers", and create a unified public image through a Future Harvest global awareness campaign. This campaign attracted the advocacy of world personalities such as ex-US President Jimmy Carter, Mohammed Yunus, M. S. Swaminathan and other notables.

Future Harvest also sponsors studies of the contributions of agricultural research to broader society, such as a recent assessment by the respected International Peace Research Institute of Oslo, Norway (downloadable from the Internet at http://www.futureharvest.org/peace/PRIOReport.shtml) that reviewed the causes of conflicts across the developing world, leading to the clear conclusion that the alleviation of hunger and poverty is essential for achieving peace and stability.

The message we must convey is that everyone today lives in an interconnected world, so investments in development protect us all from the suffering and strife, terrorism, pollution, and other ills that command the

public's prime attention today.

Legacy of the Green Revolution: high expectations

The Green Revolution set a high bar of achievement that quite possibly may never be surpassed. Nevertheless, it raised expectations for a continued flow of scientific "miracles." This legacy frames the challenge for today's generation of dedicated research and development professionals. What are our chances?

Biotechnology

The promise of biotechnology to increase crop and animal productivity while reducing pest, disease and environmental stress losses is enormous, as summarized by Serageldin and Persley (2000). Massive problems such as drought, voracious insects, physiological inefficiencies, and disease resistance breakdowns no longer seem as intractable as they once were.

The potential impacts of biotechnology are huge. But the challenges are not only biological — they are also institutional, financial, and even legal. Gordon Conway of the World Bank (Conway, 1999) argues that biotechnology can spark a "doubly green revolution" that can add further productivity gains while also protecting the environment — IF the world community provides the essential support to ensure that it is directed towards the public good.

Many patents are now being issued restricting public-sector access to such fundamental research knowledge as genes and laboratory methodologies for gene manipulation. These patents are equally restrictive towards the orphan crops of the poor, even though the private sector may have little interest in applying them towards these crops. These basic enabling technologies need to be made available so that public-sector organizations can use them to deliver their promise to the poor (Serageldin, 1999).

Here we see a key role for International Centers in the future, as neutral facilitators or "brokers" in helping negotiate the necessary arrangements between the public and private sectors. The Centers are trusted by both parties since they are independent of political or profit motives, and have historically proven their effectiveness as "bridges" and "catalysts" in partnerships between North and South.

The recent trend towards investments by the private sector in public sector research (described earlier) is a hopeful indicator that a new era of common understanding may be on the horizon. This spirit will be key to moving forward on more difficult issues such as the sharing of proprietary biotechnologies and germplasm. We are increasingly confident that we will be able to find win-win solutions that gain access for the poor to these powerful new tools, while not denying the reward that private sector investors understandably expect for their own risks and efforts.

Information and communication technology

The global revolution in information and communication technology holds equally a dazzling potential. The more complex, system-oriented solutions required of today's agricultural research-for-development are more knowledge-intensive than the simpler seed-centered technologies that drove the Green Revolution.

In the Green Revolution model, it was necessary to provide large amounts of costly inputs to "homogenize" the agro-environment so as to remove all constraints to the yield potential of high-performance varieties. In the new era, global competitiveness and production efficiency will become paramount. Information will become a key strategic resource enabling farmers to better tailor their crops and management to their particular area and conditions, extracting the most efficient use of the endowment they have at hand.

To capture the benefits of integrated natural resources management, farmers will need to juggle several components simultaneously, and make complex decisions. They will need information tools and services to

help them understand and evaluate the trade-offs, risks and rewards involved, and to make the most optimal decisions for their particular situations.

We are rapidly approaching the day when extension or farmer organization offices even in remote villages will be able to dial up the Internet over the telephone (or even the cell phone) to obtain information on input and crop commodity prices, seed availability, weather, variety and management recommendations, pest and disease epidemic forecasts, and other valuable insights.

The same channels will be used by farmers to feed back their own observations and knowledge so that researchers, policy-makers and the press will have a better understanding of realities on the ground. It will no longer be possible for governments to ignore the rural poor simply because of their geographic isolation.

Better communications will lead to stronger partnerships among research and development organizations. Virtual teams will be quickly formed through searches over the Internet, finding just the right expertise for important problems. They will meet by videoconference to share experiences, consult additional specialists, and view field situations. Just as quickly as they were formed, these teams will disband once the problem is solved, free to move on to other challenges and teams, amplifying the social benefits derived from their skills.

Conclusions

It may not be surprising that an achievement as consequential as the Green Revolution resulted in such diverse and far-reaching outcomes as those described in this paper. But its ramifications continue to affect the lives of citizens, nations, regions, and the globe to this day. Surpassing the expectations of most, yet falling short of the broad social goals of some, it remains a phenomenon held in both awe and controversy. Nevertheless, all will agree that it serves as a potent example of the power of science in service of development — which we at ICRISAT call "Science with a Human Face."

The Green Revolution bought precious time for our global village — an opportunity to bring population and environmental deterioration under control before they outrace our capacity to increase food supplies. This precious interval has enabled scientists to develop even more powerful tools that many believe will unleash a second Green Revolution: biotechnology and information/communication technologies.

If these new tools indeed fulfill their promise, we can only hope that they bring a more just, prosperous and equitable society — one that will also have gained the wisdom, knowledge and resources to bring the population and environmental degradation monsters under control. If so, then the fruit of the Green Revolution will be a harvest richer than we had ever dreamed.

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